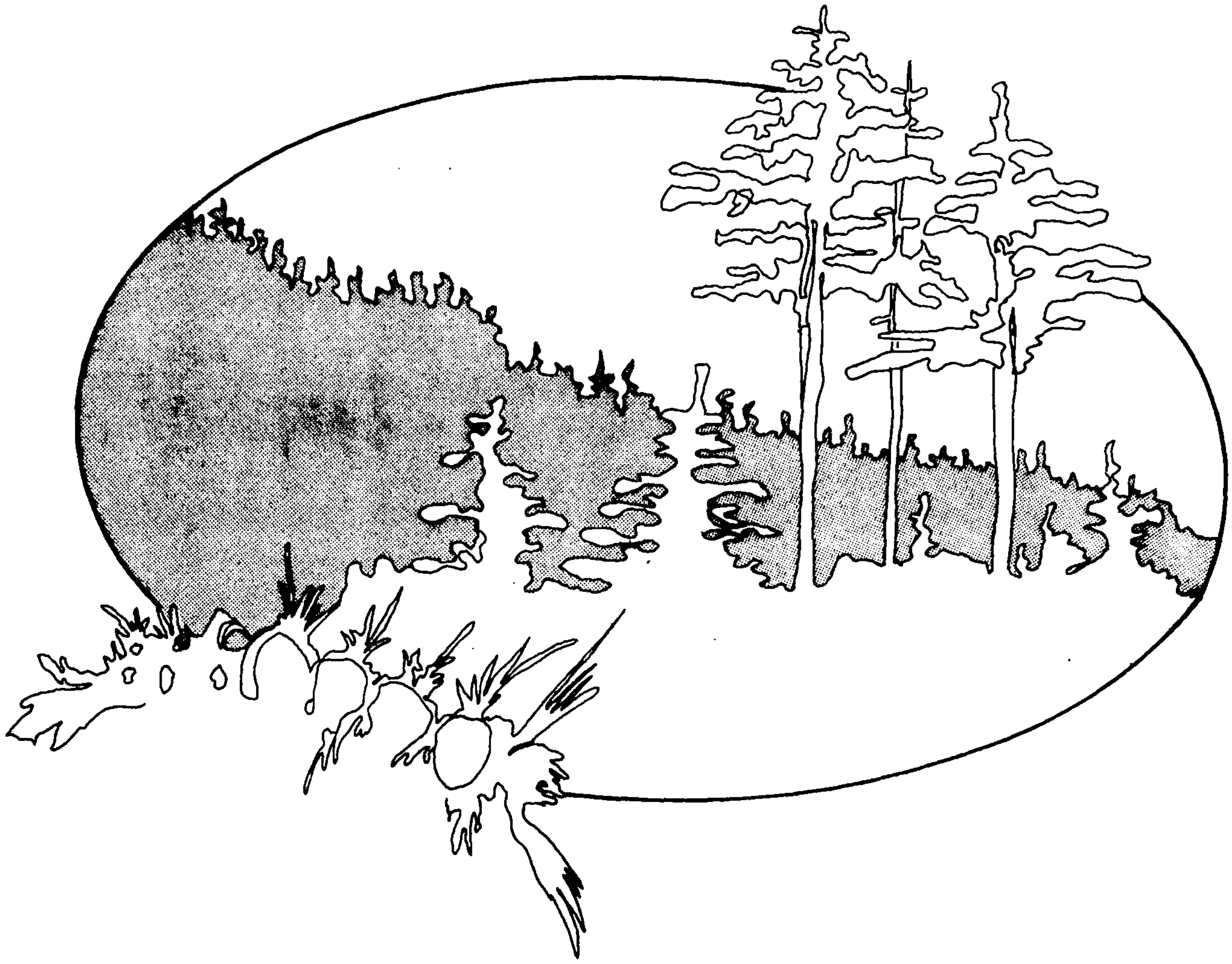
# AN EVALUATION OF THE IMPACTS OF FOREST DEFOLIATION BY DOUGLAS-FIR TUSSOCK MOTH ON FUTURE SITE PRODUCTIVITY



Final Research Report

Submitted to:

U.S.D.A. Douglas-fir Tussock Moth
Research and Development Program

by

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# FINAL REPORT

Title: An evaluation of the impact of forest defoliation by Douglas-fir tussock moth and subsequent management activities on future site productivity

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DFTM Activity No. 2.1.5 (1.1.2) Analyze effects of defoliation and tree damage on ecological impacts

Period of activity: May 1975-December 1977

## ACKNOWLEDGMENTS

The principal investigators of this study would like to acknowledge and thank the many cooperators for their valuable assistance. A project of this size also requires the assistance of a large number of other individuals and we appreciate their cooperation, suggestions and help.

Wenatchee National Forest Supervisor John Rogers, District Ranger Bill Butler and their staffs, Randy Perkins, Monte Bickford, Phil McColley, Jim Ogden, and Ernie Nelson, all were instrumental in arranging for the experimental area and helping to make this research useful to forest management.

A special note of appreciation is extended to Al Stage, Bob Monserud, and Bill Wykoff, INT Forestry Sciences Laboratory, Moscow, for their effort in computer programming and operation to match our data and requirements to the Stand Prognosis Model. The validity of the model was assisted by the site specific yield and volume tables developed by Pat Cochran, PNW Silviculture Laboratory, Bend.

Gaylon Campbell, H. H. Cheng, Walter Gardner, and Ray Gilkerson, Washington State University, Pullman, and Jack Berglund, State University of New York, Syracuse, were extremely helpful with guidance and suggestions to graduate students assigned to this project.

All of the members of the staff at the Forest Hydrology Laboratory, Wenatchee, including Bill Fowler, Dave Helvey, Bill Lopushinsky, Art Tiedemann, Tom Anderson, Don Gerber, Kay Stowers, Don Snyder, Audrey Thornton, and Blane Van Hoven participated in the project.

We are particularly appreciative of Ken Wright and Max McFadden for their support and encouragement through the USDA Expanded Douglas-fir Tussock Moth Research Program.

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## SUMMARY

Two nearly 0.4-ha forest stands of the grand fir-Oregon boxwood habitat type adjacent to Nason Creek in the Lake Wenatchee District, Wenatchee National Forest, were defoliated in the summer of 1976. The stands were chemically defoliated with Paraquat in a study designed to simulate Douglas-fir tussock moth damage. Each defoliated stand was referenced against a nearby stand of similar composition. The objective of the study was to test our hypothesis that forest defoliation by Douglas-fir tussock moth has a minimum longterm negative impact on the productivity of a forest site; in fact, defoliation may have some positive benefits in terms of wood fiber production, particularly in decadent "eastside" forest stands. To achieve our study objective, extensive monitoring and evaluation of some important contrasting abiotic fluxes including solar radiation, heat, water, and plant nutrients between chemically defoliated and reference stands were conducted through the period 1975-1977.

In each of the 0.4-ha experimental forest stands, replication one Blocks A and B and replication two Blocks C and E, instruments were installed to measure solar radiation, air and soil temperatures, and soil moisture. Solar radiation reaching the canopy was monitored above Block C. Nutrient levels of the forest floor and the underlying mineral soil were monitored at twelve randomly selected permanent sampling locations in each block prior to and again following defoliation. Inputs to the forest floor of litter were monitored before, during, and after defoliation.

Changes in the transmission of radiation to the forest floor through the forest canopy created by the defoliation treatment were measured with both solar radiation recording instruments and "fish-eye" 180-degree hemispherical photographs. Our experience showed that the hemispherical photographs are an inexpensive acceptable method for measuring the probable fraction of total solar radiation reaching the forest floor. Following simulated insect defoliation on Blocks A and C the probabilities for diffused radiation penetration increased from 21.2 to 28.1 percent and 19.3 to 35.9 percent, respectively. The differential extent of canopy opening and diffused radiation penetration under the same amount of chemical application is attributed to the influence of stand composition and crown structure. The albedo or reflectivity of the forest floor in the defoliated stand was found to be nearly twice that of the reference stands about one month after the defoliation treatment because of the color of the newly fallen needles. The albedo had dropped appreciably one year after defoliation, but had not returned to the pre-treatment level.

Daytime soil and air temperatures were found to be warmer during the summer months and cooler during the winter period in the defoliated stands. The warmer daytime temperatures appear to occur because the solar energy input going into sensible heating at the forest floor available from increases in canopy exposure exceed that solar energy input lost (reflected) by increases in the albedo of the forest floor. Air and soil temperatures were lower in the defoliated stands during the winter months due to differences in the solar angle, longwave reradiation, and canopy heat capacities. Since

the most active time period of microbiologic activity and possible subsequent plant nutrient availability is during the spring and summer, lower winter temperatures appear inconsequential in this respect. However, plant physiologic responses, snowmelt, and possible wildlife activities may be affected.

Using the radiation and temperature data measured at the experimental site, a nomograph was developed to predict the soil temperature threshold level relationship between canopy defoliation and solar radiation reaching the top of the forest canopy. Although the relationship is only valid for the Nason Creek experimental site without further testing, we appear to be able to predict for a measurable level of defoliation the minimum levels of radiation reaching the forest stand which will modify soil temperatures at the 2.5-cm depth.

Different rates of soil water depletion in the defoliated stands due to changes in the stand's evapotranspiration requirements were observed immediately after chemical defoliation and continued through the summer and fall months. In the following year, after soil profile recharge by the winter precipitation, soil water depletion rates in the defoliated stands were significantly less from early spring through late August, after which substantial early fall precipitation reduced depletion rates. Seasonal differences in the soil water depleted in the upper 1.5 m of the soil profile between the defoliated and control stands were 12.1 to 14.5 cm.

Defoliation had a significant influence on the plant nutrient flux rates between the forest canopy and the forest floor. Following defoliation nearly ten times as mcuh nitrogen as well as other nutrients were returned

to the forest floor when compared to the control stands. The additional nitrogen returned to the forest floor by defoliation is equivalent to an approximate 5-year requirement by a mature Douglas-fir stand.

Defoliation resulted in no statistically significant effects on soil nutrient status in the first 15 months following defoliation, although extractable potassium levels appeared to increase in both defoliated plots to a greater extent than the normal overwinter increase evidenced by the control plots. As potassium (and, to a lesser extent, phosphorus) levels of the recently deposited needles in the defoliated plots had already decreased substantially during the first overwinter period, the slight increase in extractable soil potassium levels may reflect the first demonstrable soil chemical changes associated with defoliation. Despite the large amount of nitrogen added as recently deposited needles in the defoliated plots, and the more favorable temperature and moisture conditions for microbial activity, no appreciable change in soil mineral nitrogen levels was evident following defoliation. Hence, only physical and chemical processes (e.g., the leaching of potassium and some phosphorus), and not microbial processes, were in evidence during the study period. The increased nutrient content of the forest floor in the defoliated areas may provide for eventual changes in soil nutrient status following breakdown of the needles and release of nutrients to the underlying soil.

The possible effects of defoliation on the longterm growth of the trees in Blocks A and C were tested with a Stand Prognosis Model for the period 1977-2027. Over a 50-year period total additional volumes predicted were shown to be greater following defoliation than under normal stand conditions. Probably more important is the fact that volumes in the defoliated stand condition appear to equal or exceed that of a non-defoliated or unaffected stand in about 35 to 40 years following defoliation, even with an initial mortality loss of 11 to 21 percent of the volume. If we attempt to account for changes in the abiotic fluxes and their possible influences in growth with the model for our experimental stands, volumes are equal or exceed the unaffected stands in 20 to 25 years. Significant volumes of wood fiber are also available for salvage logging through immediate mortality in the defoliated stands.

Many factors other than those that can be predicted by models can affect a stand's growth over a 50-year period in the future. However, it does appear through the use of models, defoliation of stands similar to those tested in this study by phytophagous insects may have some positive effects on a forest site's productivity. In our final evaluation of data contained in this report, we must conclude that a modification of forest primary production by phytophagous insects often appears to resemble thinning and mineral fertilization, an acceptable stand improvement silvicultural activity.

# INTRODUCTION

Figure 1 is an illustration of the growth of a 94-year-old Abies grandis tree on the Wenatchee National Forest. We highly suspect that this tree was defoliated by insects near age 21, when its rate of growth was severely reduced for roughly 8 years. After this time, growth increased dramatically once more to a growth rate even greater than that prior to the attack. Many factors could have influenced this growth acceleration including the genetic composition of the tree itself. We believe that other key factors which may have led to accelerated growth, however, include increased nutrient availability, improved soil water relations, and solar energy redistribution within the stand. Modification of any of these factors by outside initiators such as the Douglas-fir tussock moth can have significant influences on forest site quality. This may, in turn, lead to changes in the future productivity of the site.

Mattson and Addy (1975) postulated that insect defoliation can alter the distribution and relative availability of abiotic fluxes (light, heat, moisture, nutrients, carbon dioxide, wind, etc.) within a plant canopy. Because needles are an important component of a conifer forest canopy, their removal by insect defoliation should have a significant influence on solar radiation distribution as well as on other abiotic fluxes within a forest stand. After defoliation, a larger proportion of the solar radiation input to the forest canopy should reach the forest floor, thereby modifying the forest floor temperature regime. Modifcation of forest temperature regimes should affect subsequent biologic activity, as well as evaporation and snowmelt rates. With possible changes in forest floor biologic activity and water increased nutrient loading because of frass deposition and increased needle casting, significant changes in plant

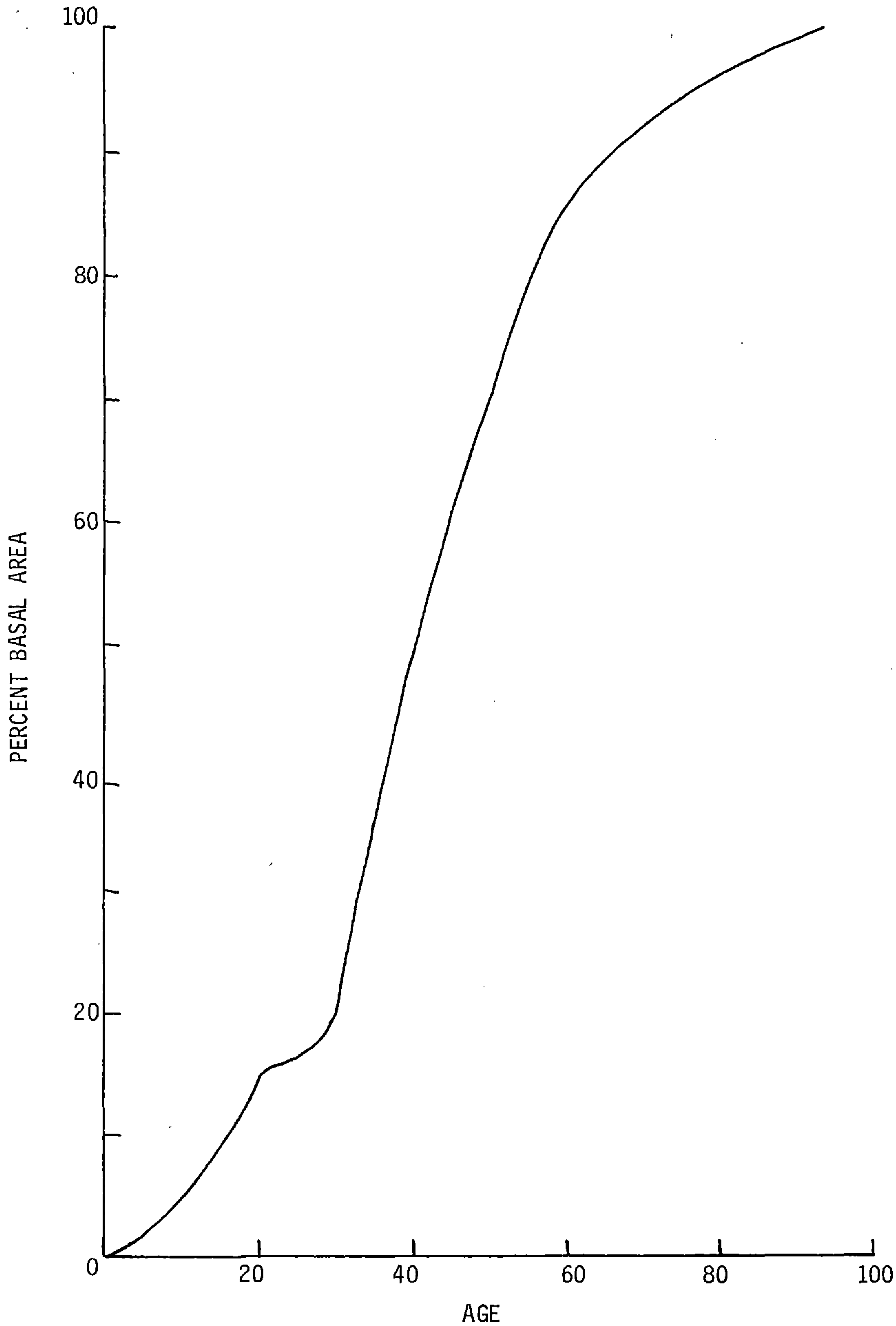



FIG. 1. THE BASAL AREA ACCUMULATION OF A 94-YEAR-OLD <u>ABIES GRANDIS</u> TREE WHICH APPEARS TO HAVE HAD ITS GROWTH RATE AFFECTED BY INSECT ACTIVITY NEAR THE AGE OF 21.

nutrient cycles may occur within a forest ecosystem following insect-induced defoliation. On a longterm basis, nutrient cycling will also be modified by accelerated return of woody materials to the forest floor because of insect mortality. Water content of the soil profile may also be altered following defoliation, with water content increases being most probable, due to reduction both in plant transpiration and in precipitation interception. Higher soil moisture contents could influence biologic activity rates, as well as affecting the mobility of many plant nutrients within the forest floor and lower mineral soil.

From the field observation discussed above, from the findings of earlier research, and from our general knowledge of the forest soil-water-plant continuum, we hypothesized that forest defoliation by Douglas-fir tussock moth should have a minimum negative impact on the productivity of a forest site, and that defoliation might even have some positive benefits in terms of increased longterm vegetative growth and wood fiber production. To test our hypothesis, we have conducted extensive ecologic impact research with the following objectives:

(1) To quantify and evaluate some direct impacts of defoliation from simulated insect activity (Douglas-fir tussock moth) on forest site quality by

(a) examining changes in radiation distribution within the forest stand as a result of defoliation and its effect both on soil moisture and on soil and air temperature regimes,

(b) examining changes in plant nutrient content and availability of the forest floor and underlying mineral soil as a result of defoliation.

(2) To evaluate some of the impacts of forest management activities, with emphasis on salvage logging and residue treatments, on site quality of Douglas-fir tussock moth-defoliated forest lands.

All research to test objective (1) was conducted at an experimental site adjacent to Nason Creek in the Wenatchee National Forest. Research on objective (2) was conducted in the Blue Mountains of Oregon in the Umatilla and Wallowa-Whitman National Forests.

## METHODS AND EXPERIMENTAL DESIGN

### Experimental Site Location and Plot Design

The Nason Creek experimental site was located about 20 km east of Stevens Pass on Highway 2 in the Lake Wenatchee Ranger District. The site is in Section 7, T. 26 N., R. 17 E., with latitude 47$^{o}$ 45' N and longitude 120$^{o}$ 45' W. The elevation is about 640 m above mean sea level. The study area is on a terrace of recent glacial outwash (10,000-15,000 years BP) about 35 m above Nason Creek, a tributary of the Wenatchee River. The soil is a Wintoner loam and lies on a southwest-facing slope of about 8% (see Appendix A for soil profile description). Average annual precipitation is estimated at 90 cm, of which approximately 75% occurs as winter snow. Less than 5 cm of precipitation is generally expected during the June 15-September 15 period.

The habitat type for the experimental site is classified as grand fir-Oregon boxwood (*Abies grandis*-*Pachistima myrsinites*), with grand fir (*Abies grandis* (Dougl.) Lindl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) as major tree species. The overstory is approximately 60% grand fir, 35-38%

Douglas-fir, and 2-5% ponderosa pine (<u>Pinus ponderosa</u>, Laws). Vine maple (<u>Acer circinatum</u>, Pursh) is an important understory component. Although the stand is considered to be relatively even-aged, tree ages range from 20 to 140 years, with 55-60 years being the mean age. Mean tree height is approximately 25 m. Basal area ranged from 62.2 to 96.6 $m^2$/ha (271 to 421 $ft^2$/A).

Within the experimental stand four experimental blocks were established in 1975. Replication consisted of two blocks 64 x 64 m square, identified as A and B, respectively. Replication 2 consisted of two blocks 52.5 x 52.5 m square, identified as C and E, respectively. Blocks were positioned within the stand as shown in Figure 2. Distance between the replicated blocks was approximately 200 m. Different block size was used between replications to maintain control and treatment block homogeneity on the landscape.

Twelve permanent sampling plots, each 2.76 x 2.76 m square, were randomly located within each experimental block. Randomization of sample plots was carried out by locating four plots along each of three transects, using distances between transects and between plots which were chosen from a random number table. Each plot was oriented around the preselected randomized sampling point in order to avoid tree stems and other obstructions within the sampling area. Each sampling plot was divided into 36 square subplots, each 46 cm on a side, which served as sampling points for subsequent destructive soil sampling and as microclimate measurement locations (Figure 3). These subplots were the actual sampling units for each sampling period.

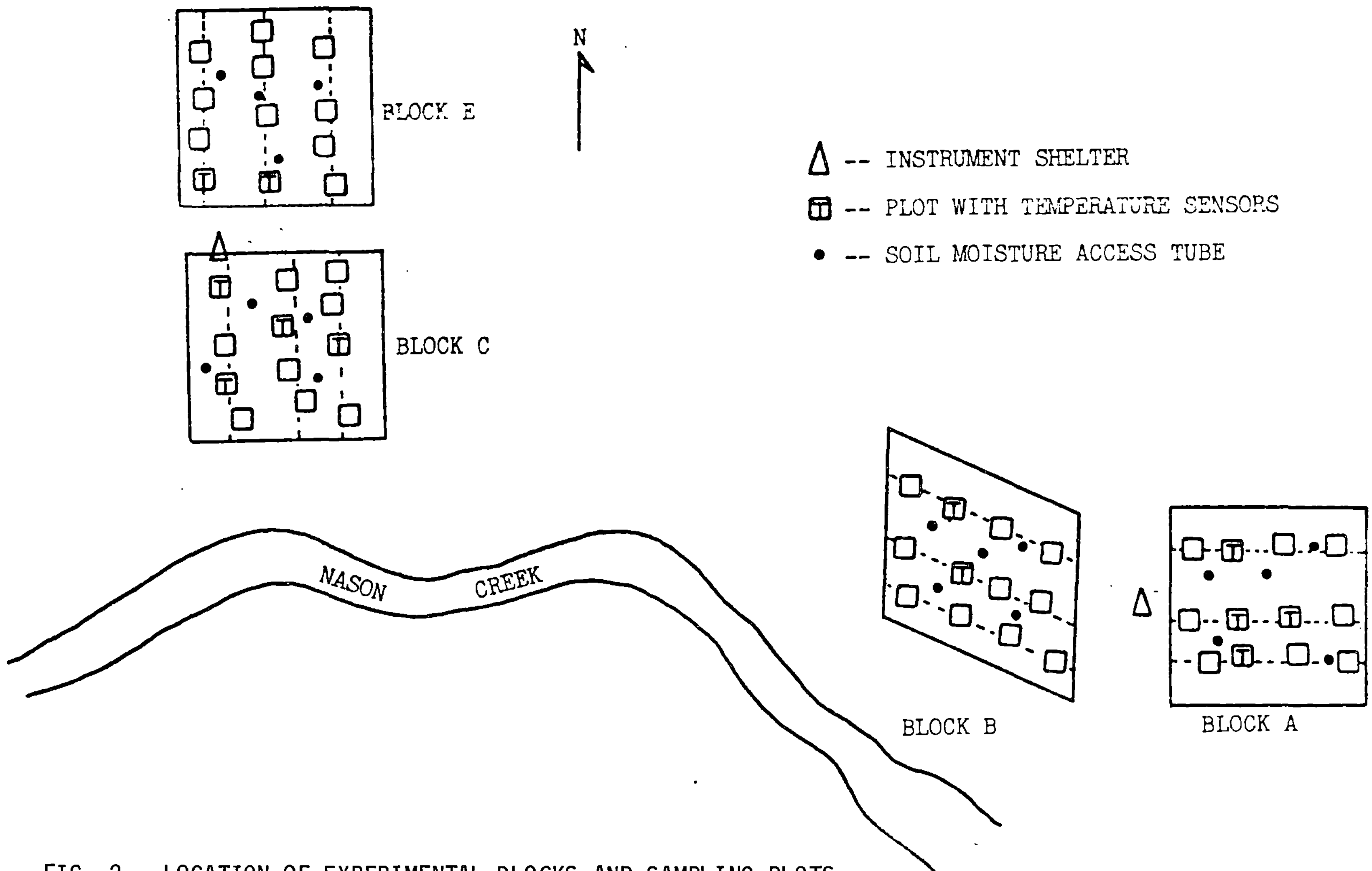



FIG. 2. LOCATION OF EXPERIMENTAL BLOCKS AND SAMPLING PLOTS.

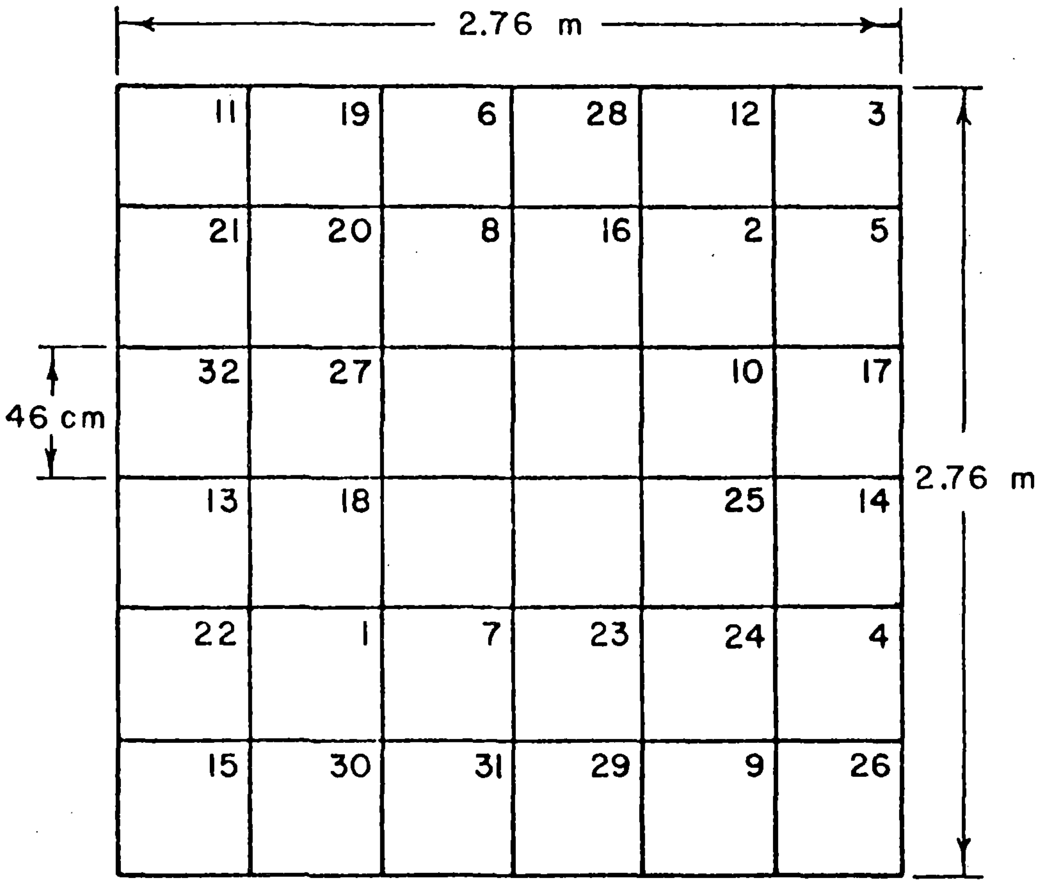



FIG. 3. TYPICAL SUB-PLOT ARRANGEMENT.

Defoliation

It would have been ideal to have an experimental location where studies could have been conducted before and after an actual Douglas-fir tussock moth attack. Such conditions were not available within the time frame and travel distance constraints on the project, however. Thus, artificial defoliation with chemicals was used to carry out our study objectives.

From June 1975 to June 1976, comparative measurements of various physical and chemical parameters were made between sampling plots of each block and each replication. On June 28, 1976, Blocks A and C were each sprayed by helicopter with 0.91 kg of Paraquat (1,1'-dimethyl-4, 4'-bipyridylium dichloride) and 0.5 liter of Chevron X-77 spreader mixed with 380 liters of water. Care was taken to keep all spray within treatment block boundaries by using a large spray-drop size under windless, early morning conditions. Each of the 12 sampling plots were covered with a plastic barrier in order to prevent any possible effects of the Paraquat or the spreader on biologic activity of the site. Immediately following this first application of Paraquat, the ponderosa pine needles dessicated and turned brown. The understory vine maple was also severely affected. However, the firs, and particularly the grand fir, showed only minor evidence of needle damage from this treatment.

Further observations indicated that the spreader content was not high enough to keep the Paraquat on the highly waxed needles of the fir long enough for effective penetration. Thus, a second application of Paraquat was made on July 27, 1976, using 0.91 kg of Paraquat and 4 liters of X-77 spreader mixed in 190 liters of water. The effect of the second treatment was immediately observable, with extensive fir needle drop beginning in less than a week. The intensity of subsequent needle fall depended mainly on wind conditions.

Large amounts of needle fall occurred whenever the canopies were being vigorously agitated. The majority of the needles fell during the month of August 1976. Freshly fallen needles extensively covered the forest floor of the treatment blocks, with depths reaching nearly 2 cm by late September. This depth was reduced to less than 1 cm by compaction from snow during the winter months.

The chemical defoliation treatment was designed to defoliate but not to kill the trees. This was generally the case. However, newly emerging foliage in the early summer of 1977 was badly eaten by an infestation of western spruce budworm. Tree survival will probably be lower than expected from the Paraquat defoliation alone. Damage to the control blocks by the western spruce budworm was not apparent.

Radiation Studies

Two approaches were used to evaluate the radiation regime above and within the experimental stand. Actual measurements of incoming solar radiation were made both above the canopy and at the forest floor. Indirect estimations of radiation penetration were also obtained by canopy picture analysis. The Moll-Gorczynski pyranometer, also known as the "Kipp" radiometer, was used for measuring total solar radiation. Total solar or sky radiation reaching the top of the canopy was measured by a pyranometer mounted on the top of a 26 m tower located in Block C. Incoming radiation at the forest floor was monitored by a similar pyranometer placed at the center of each sampling plot for a period of two to seven days.

All radiation data were to be integrated and logged on Wescor DL-520 data acquisition systems which were to have been delivered in late summer. However,

the data loggers did not arrive until February of 1977. Hence, the 1977 data were recorded as intended, with excellent results. The 1975 and 1976 data, however, had to be taken with borrowed, improvised and manual equipment which did not always provide the planned measurement flexibility.

During 1976, radiometers above the canopy and on the forest floor were simultaneously registered on integrator-pause counters. In 1977 the same data were recorded on the DL-520 data acquisition system. Radiant energy inputs for two- to seven-day periods were calculated from the equation:

$$I = \frac{X}{(A/10) \times B} \times 60,$$

where

$I$ = total incoming radiation over the specific period, $cal/cm^2$

$A$ = calibration for recorder, counts/hr-10mV

$B$ = calibration for pyranometer, $mV/cal\text{-}cm^{-2}\text{-}min$

$X$ = total counts over the sampling period

On September 2, 1976, and on June 30, 1977, albedo (shortwave reflectivity) of the forest floor was measured from the ratios of pyranometer outputs while facing downward and while facing upward when positioned 1 m above the ground. Random point readings were made within each experimental block on each of these dates.

Hemispherical canopy pictures were taken with a Nikon 180$^{o}$ equidistance "fish-eye" lens attached to a Nikkormat FT2 35 mm camera. Kodak Ektachrome high speed film with an ASA rating of 160 was used. The exposure setting was adjusted so that terrestrial objects were correctly exposed, resulting in overexposure of the sky. The camera was leveled on a platform less than 5 cm

above the surface at the center of each plot, to assure that the axis was pointing vertically to the sky. True north was identified with a vertical rod attached to the platform. On June 8, 1976, under overcast sky conditions, canopy pictures were taken on all 12 plots in Blocks A, B, C, and E. After defoliation, on September 10, 1976, canopy pictures were taken on the 24 plots in the defoliated blocks (A and C).

As the hemispherical pictures were taken on positive film, a slide projector was used for evaluation of the pictures. A spiderweb grid screen with grid lines at every $10^{o}$ elevation angle and $7.5^{o}$ azimuth angle was prepared (Figure 4). Care was taken to avoid distortion of the projected image on the screen. Since the lens used was an equidistance lens, each sector of the grid represented an equal area in a hemisphere above the horizon centered at the point where the camera was placed. The rating of probability for diffuse radiation penetration for each sector was arbitrarily estimated, based on a 5-point scale: 0 - canopy elements fill essentially all of the sector; 1 - elements fill about 75% of the sector; 2 - elements fill about 50% of the sector; 3 - elements fill about 25% of the sector; 4 - sky fills essentially all of the sector. The average probability of radiation penetration ($P\phi$) for each elevation angle ($\phi$), was determined by adding the scores for each elevation and dividing by 192 (48 x 4). A summation formula was used to compute the average probability for diffuse radiation penetration (X) for the entire hemisphere:

$$X = \Delta\phi \sum_{\phi=\phi_o}^{\phi n} P\phi \sin \phi,$$

where $\Delta\phi$ is the elevation angle increment in radians, equal to 0.175 as $10^{o}$ is the elevation angle increment.

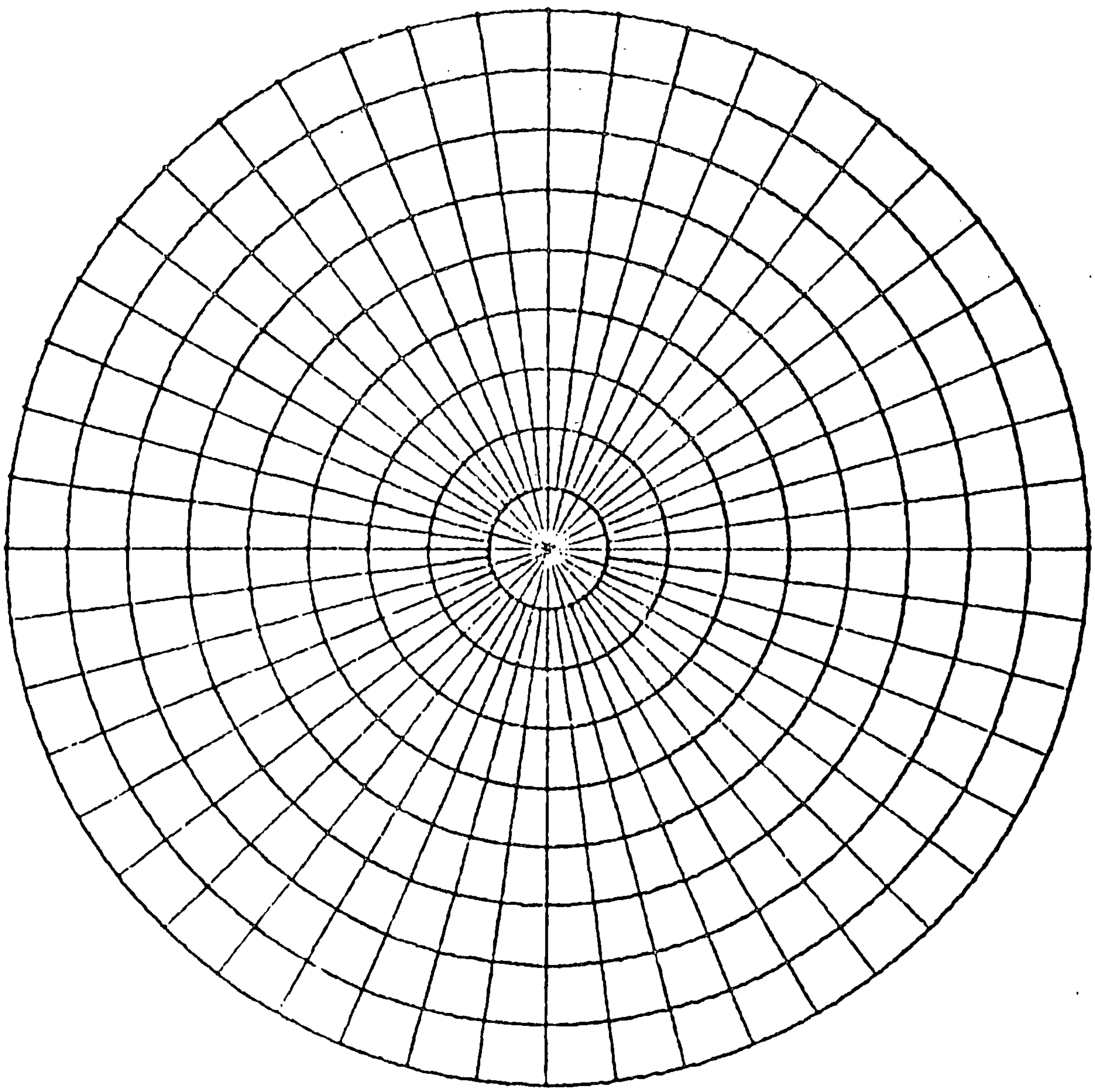


FIG. 4. GRID USED FOR HEMISPHERICAL CANOPY PICTURE ANALYSIS.

The analysis of hemispherical canopy pictures was difficult. With experience and the aid of a calculator, the total scores for each elevation angle segment could be obtained readily if the penetration for each individual azimuth angle segment within the elevation angle was not required. An experienced analyst could evaluate a single photograph in approximately 10 to 15 minutes.

Temperature and Soil Moisture Studies

Both air and soil temperature were monitored in the study. Copper-constantan thermocouple temperature sensors were constructed and installed in the field during the summer of 1975. Four plots from each defoliated block (A and C), and two plots from each control block (B and E) were randomly selected for installation of the thermocouple sensors (Figure 5). At each plot, sensors were placed at seven different levels: i.e., at 1-m and 10-cm elevations above the soil and at the 0-, 2.5-, 7.5-, 15-, and 30-cm depths beneath the forest floor-mineral soil interface, respectively. The temperature sensors at the 1-m and 10-cm above ground elevations were shielded with white painted pie pans to avoid radiation heating. They were installed at the center of the north edge of the sampling plots. All soil temperature sensors were buried in the center of the same plots (Figure 5).

All field sensors were cabled into an instrument shelter located between each set of plots. The cables from the plots to the instrument shelter were shielded by 2.5-cm I.D. PVC plastic tubes, for protection from damage by foot traffic or rodents. In 1976, two 10-channel Wescor DL-510 analog data acquisition systems were used for recording temperature data. Temperature

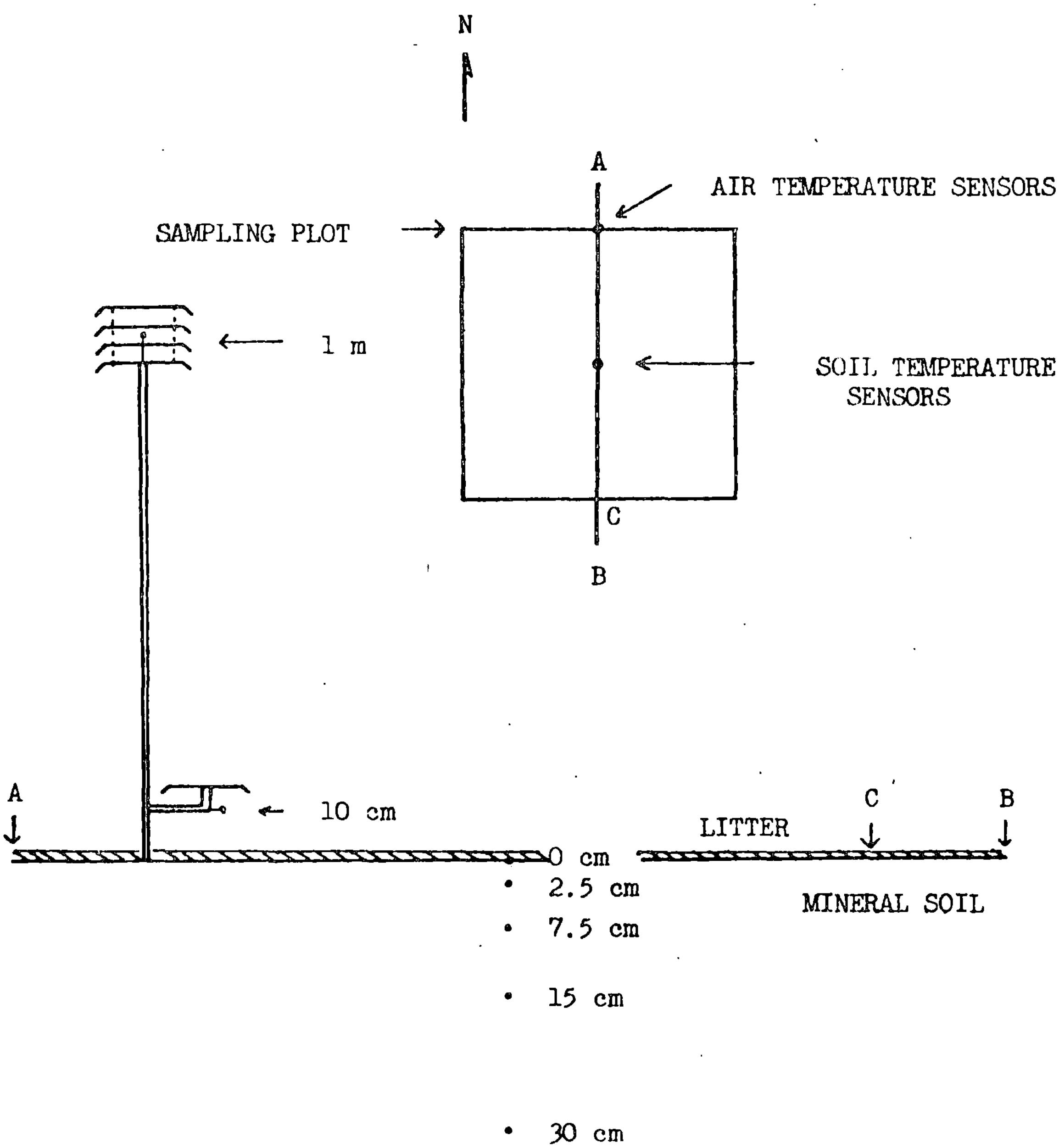



FIG. 5. POSITIONS OF THERMOCOUPLE TEMPERATURE SENSORS.

readings were automatically scanned at 2-hour intervals and recorded on paper tape. Because of constraints imposed by these data loggers, only 27 sensors were continuously monitored in Blocks A and B, and nine sensors in Blocks C and E, throughout the summer of 1976. The remaining sensors were monitored only periodically. All 1976 temperature readings were from the June to mid-September period.

In February of 1977, the 20-channel Wescor DL-520 digital data acquisition systems which had been ordered in 1975 were finally available. Thus, all temperature as well as radiation sensors installed in all experimental blocks could be monitored at 1-hour intervals from February through November 1977. While data obtained in 1976 had to be graphically interpreted in order to determine temperatures at intervals of $0.1^{o}$ C, the 1977 data were directly printed by the recorders at $0.1^{o}$ C intervals. Because a larger number of sensors could be monitored with greater precision at more frequent intervals in 1977 than in 1976, the reliability of the 1977 data was much greater. Enough data were still obtained in 1976, however, to permit determination of relationships between sampling points within the blocks and among blocks as the season progressed.

The neutron scattering method was used to measure profile soil moisture contents periodically through the aid of a Troxler 2606 portable scaler and a Troxler S6A neutron probe. Aluminum tubes, each 180 cm long and 5 cm I.D., were randomly installed at the experimental site, with five tubes each in Blocks A and B, four tubes each in Blocks C and E (Figure 2). Measurements were made at 2- to 3-week intervals from May 5 to October 16, 1976, and at 2-week intervals from April 16 to November 2, 1977. Readings were taken at

30-cm depth intervals, beginning at the 30-cm soil depth. Moisture contents on a volume basis were computed for each profile on each sampling date. Soil moisture contents of the surface 30 cm were also measured gravimetrically on each date of soil and forest floor sampling for chemical analysis.

## Forest Floor and Soil Sampling

The forest floor and underlying mineral soil were sampled for weight, water content, and chemical composition throughout 1975, 1976, and 1977, as shown in Table 1. Sampling locations were randomly selected from the 46-cm square subplots within each of the 12 plots of each block. All samples collected from each plot on a given sampling date were from the same randomly number subplots. No samples for chemical analysis were collected during June and July of 1976 because defoliation was being carried out at this time.

Forest floor samples consisted of all organic material from a 30.5 x 30.5 $cm^2$ area down to the mineral soil surface. Samples were placed in unsealed plastic bags and refrigerated at $3^oC$ until they could be dried for at least 5 days in a forced-draft oven at $50^o$ C, weighed, and ground to pass a 40-mesh screen. Only obvious clods of soil were removed.

Composite soil samples were obtained from four depth ranges: 0-3, 3-7.5, 7.5-15, and 15-30 cm. Samples were placed in plastic bags and refrigerated at $3^o$ C until they could be dried in a forced-draft oven at $50^o$ C for 24 to 48 hours and ground to pass a 1-mm sieve. Subsamples of the samples from each soil depth were placed in aluminum moisture cans in the field, for subsequent gravimetric determination of moisture contents.

Table 1. Sampling dates employed.

| Date | Samples Collected | Blocks Sampled |
|---|---|---|
| July 15-16, 1976 | Soil, forest floor, mineral and moisture samples | A, B |
| August 4-7, 1975 | Soil, forest floor, mineral N, moisture, and bulk samples | All |
| September 1-3, 1975 | Soil, forest floor, mineral N, and moisture samples | All |
| October 4, 1975 | Soil, forest floor, mineral N, moisture, and bulk samples | All |
| November 1, 1975 | Mineral N and moisture samples for depths 0-3 and 3.75 cm | All |
| May 15, 1975 | Soil, forest floor, mineral N, moisture, and bulk samples | All |
| June 7, 1976 | Moisture samples | All |
| August 10, 1976 | Soil, forest floor, mineral N, and moisture samples | All |
| September 2, 1976 | Soil, forest floor, mineral N, and moisture samples | All |
| October 2, 1976 | Soil, forest floor, mineral N, moisture, and bulk samples | All |
| April 29-30, 1977 | Soil, forest floor, mineral N, moisture, and bulk samples | All |
| June 2-3, 1977 | Moisture samples | All |
| June 29, 1977 | Soil, forest floor, mineral N, and moisture samples | All |
| August 3, 1977 | Mineral N and moisture samples | All |
| September 7, 1977 | Mineral N and moisture samples | All |
| October 1, 1977 | Soil, forest floor, mineral N, moisture and bulk samples | All |

Soil samples for mineral nitrogen determinations were obtained from the 0-7.5-cm depth, placed in plastic bags, and transferred to an ice chest within 2 hours of sampling. They were transported to the lab the same day and stored at -20° C until they could be dried for 4 hours in a forced-draft oven at 60° C and ground to pass a 1-mm sieve.

Bulk soil samples for bioassay analysis were obtained from the 0-15 cm-depth, generally on the May and October sampling dates each year. Samples were returned to the laboratory and air-dried as soon as possible.

### Forest Floor Analyses

Forest floor samples were prepared for calcium, magnesium, potassium, and phosphorus determinations by means of dry combustion (Piper, 1944) at 500° C for 5 hours. After being reweighed to determine mineral content, ashed material was suspended in 5 ml of 2N HCl, heated to 60° C for 4 to 5 minutes, and then transferred to 50-ml volumetric flasks. Filtered extracts were used for determination of each of the elements listed.

Calcium and magnesium were determined by means of a Jarrell Ash atomic absorption spectrophotometer, using an oxygen-hydrogen flame with 1500 ppm strontium chloride as an interference suppressor. Potassium was determined with a Beckman DU flame photometer, using an oxygen-hydrogen flame and reading emission at 767 nm. Phosphorus was determined by means of a stannous chloride-molybdate blue colorimetric procedure, using a Bausch and Lomb spectrophotometer set at 520 nm (Olsen and Dean, 1965). Total nitrogen was determined following micro-Kjeldahl digestion with a mercuric oxide-potassium sulfate-sulfuric acid digestion mixture. Analysis of the resulting solution was by means of a Technicon Auto-Analyzer II system, using salicylate-nitroprusside-hypochlorite reactions and reading the resultant color at 660 nm in a spectrophotometer (Conetta *et al*., 1976).

Soil Analyses

Soil moisture contents were determined gravimetrically, using 100-300 g of moist soil which had been put into sealed moisture cans in the field. Samples were ovendried at $105^{o}$ C for 24 hours. pH was determined with a Beckman pH meter after equilibration of a 1:2 w/v (soil:distilled water) mixture for a minimum of 1 hour.

Analyses for extractable calcium, magnesium, potassium, and phosphorus were conducted on N NaOAc (pH 4.8) soil extracts at a soil:solution ratio of 1:5 (Peech and English, 1944). Suspensions were shaken for 30 minutes, with filtered extracts being stored in a refrigerator at $3^{o}$ C for a maximum of 1 week prior to analysis. Analyses for the four elements employed the procedures previously described in the forest floor analysis section, except that phosphorus was determined in a Bausch and Lomb spectrophotometer using a red filter and a setting of 644 nm.

Total nitrogen was determined by the procedure described in the section on forest floor analyses. Oxidizable organic matter was determined by a modified Walkley-Black procedure without external heating (Moodie and Kochler, 1973).

Mineral nitrogen was determined using a 2N KCl extractant and a soil: solution ratio of 1:2. This ratio was lowered from the ratio of 1:10 (Bremner, 1965) in order to provide sufficiently concentrated solutions for accurate determinations. The suspensions were shaken for 1 hour, with the filtered extracts then being analyzed for both ammonium-N and nitrate-N on the Technicon Auto-Analyzer II system. Ammonium-N was determined as described for the total nitrogen determinations on forest floor samples. Nitrate-N was determined by reducing the nitrate to nitrite by means of a copper-cadmium

reductor column and then using a sulfanilamide-N-1-naphthlethylenediamine dihydrochloride reaction to produce a reddish-purple solution which could be read at 520 nm in a spectrophotometer.

Bioassay analyses were conducted by growing five Douglas-fir seedlings in 15-cm diameter pots containing 1300 g of bulk soil mixed with perilite for 6 months under lighted greenhouse conditions. Pots were watered to the point where they just started to drain, to prevent loss of nutrients. Seedlings were harvested, ovendried at $50^{0}$ C, and weighed to determine overall relative productive capabilities of each bulk soil sample.

Soil bulk densities were determined by measuring the mass of a known volume of soil. Soil samples were collected with a core sampler. Texture analyses were by the hydrometer method.

Litter fall was assessed from six 1-m-square nylon screen traps placed in each experimental block. The 6-months accumulation on each trap was removed on May 1 and on November 1 during both 1976 and 1977. The samples were air-dried and separated into needles, wood, and other (cones, lichens, etc.). They were ground to pass through a 100-mesh screen for subsequent chemical analyses.

## Forest Management Activity Studies

A general survey was made of soil conditions following selective logging of DFTM-infested trees on more than 40 salvage timber sales on the Umatilla and Wallowa-Whitman National Forests in northeastern Oregon. Five study sites were chosen as having conditions representative of most salvage operations on National Forest lands in this region. Tractors had been used for log skidding at all five locations. Although some cable systems were also being used, the

land area being logged by this method was too small and variable to effectively evaluate soil impacts. The four study areas in the Umatilla National Forest were located at Red Saddle, Spring Mountain, Bobsled Ridge, and North High Ridge. The area studied in the Wallowa-Whitman National Forest was at Kuhn Ridge. Location and other details of the study area are provided in Table 31.

Survey data were obtained in June and September of 1975 on randomized plots measuring 0.37 square meter. Plot location was established by following linear compass or extend transects every 30 to 40 meters from one edge of the logged area to the opposite edge. Randomized plots were located along each transect, with an average distance between plots of 13.7 meters. A plot frame defining the sample point was dropped immediately in front of the recorder after the preselected distance along each transect had been traversed. Three to five recorders were used, independently of one another, on different contours.

At each plot the extent of soil disturbance and amount of surface cover by vegetation and logging residue were measured, generally following the classification established by Dyrness (1965). Slope, aspect, and vegetation type were also recorded. Soil disturbance levels were: (1) undisturbed (litter and top soil still in place), (2) slightly disturbed, and (3) deeply disturbed (surface soil removed and subsoil exposed). Soil disturbance on areas defined as deeply disturbed was greater than that generally thought necessary for natural conifer regeneration.

# RESULTS AND DISCUSSION

## Radiation Regimes

Measured solar radiation reaching the top of the canopy and forest floor from May 24 to June 22, 1976, is shown in Table 2. A computer program suggested by Swift (1976) was used to calculate potential daily solar radiation at the experimental site. The program was modified so that hourly values from sunrise to sunset could also be calculated. Potential solar radiation, shown in Column 6 of the table, was obtained by assuming "whole" day values and hourly values for the beginning and ending days in our calculations. Systematic errors would be encountered due to the discrepancy between recording actual time (Pacific Standard Time) and theoretical solar time. This error is relatively small when potential solar radiation for only a 2- or 3-day period is to be calculated.

The atmospheric transmission factors, which are the ratios of actual to potential solar radiation, are shown in Table 2. They range from 28.4 to 67.5%, with a mean of 51.7% and a standard deviation of 12.9%, for the periods when 1976 radiation measurements were being made. In 1977, the corresponding range was from 12 to 77%. The transmission factor of the astmosphere for solar radiation varies both with time and with atmospheric conditions because it is a function both of radiation path length through the atmosphere and of the amount of suspended materials present in the atmosphere. The atmospheric transmission factors presented here are actually integrated values for the specified periods. Variations between monitoring periods are most likely due to variations in atmospheric water content. Other factors, including solar elevation and suspended materials other than water molecules, are not likely to change significantly over short periods of time.

TABLE 2. SOLAR RADIATION MEASUREMENTS IN 1976 ABOVE AND BELOW THE FOREST CANOPY, ALONG WITH ASSOCIATED CANOPY AND ATMOSPHERIC TRANSMISSION FACTORS.

| Sampling plot | Monitoring period (Pac. Std. Time) | Total hours | Radiation above canopy ($cal/cm^2$) | Radiation on forest floor ($cal/cm^2$) | Potential* solar radiation ($cal/cm^2$) | Canopy+ transmission factor (%) | % Transmission as estimated from canopy picture | Atmospheric‡ transmission factor (%) |
|---|---|---|---|---|---|---|---|---|
| C-1 | 6-9-1000<br>6-11-1000 | 48 | 1260 | 247 | 1977 | 19.6 | 14.5 | 63.7 |
| C-2 | 5-28-1000<br>6-1-1000 | 100 | 2028 | 488 | 4071 | 24.0 | 25.9 | 49.8 |
| C-3 | 6-4-1000<br>6-7-1000 | 72 | 1661 | 340 | 2946 | 20.5 | 21.3 | 56.4 |
| C-4 | 6-7-1000<br>6-9-1000 | 48 | 889 | 245 | 1972 | 27.5 | 20.4 | 45.1 |
| C-5 | 5-24-1000<br>5-26-1000 | 48 | 829 | 236 | 1919 | 28.5 | 9.4 | 43.4 |
| C-6 | 5-26-1000<br>5-28-1000 | 48 | 783 | 251 | 1921 | 32.0 | 27.3 | 40.7 |
| C-7 | 6-1-1400<br>6-4-1000 | 68 | 1708 | 321 | 2530 | 18.8 | 21.3 | 67.5 |
| C-8 | 6-14-1100<br>6-18-1500 | 100 | 2498 | 470 | 4368 | 18.8 | 21.0 | 57.2 |
| C-9 | 5-20-1500<br>5-24-1000 | 91 | 1231 | 331 | 3312 | 26.9 | 22.4 | 37.2 |
| C-10 | 6-11-1000<br>6-14-1100 | 73 | 1962 | 417 | 3074 | 21.3 | 11.5 | 63.8 |
| A-3 | 6-18-1500<br>6-20-1300 | 46 | 1216 | 237 | 1805 | 19.5 | 21.2 | 67.4 |
| A-7 | 6-20-1300<br>6-22-1300 | 48 | 566 | 185 | 1992 | 32.7 | 25.3 | 28.4 |

* Estimated from Appendix C and D

\+ (Radiation on forest floor/radiation above canopy) x 100

‡ (Radiation above canopy/potential solar radiation) x 100

The solar radiation transmissibility of the forest canopy was obtained from the ratio of radiation measured at the floor to that measured at the top of the forest canopy. These data are also presented in Table 2, as are comparable data from hemispherical photographs for the probability of diffuse radiation penetration. Average canopy transmission factors for ten of the Block C plots were 23.8% from actual pyranometer measurements and 19.5% from estimation by canopy picture analysis. Photographic data for plots C-5 and C-10 deviated appreciably from the mean for Block C plots, but corresponding radiation measurements at the same position did not show the same deviation. The photographs showed an appreciable amount of light-colored understory vegetation in the two pictures, and particularly at location C-5. The evaluation technique used for the photographs treated all vegetation as opaque, whereas actual radiation measurements would be affected both by light transmitted through and light reflected from understory vegetation. Thus, differences might be anticipated when understory vegetation varies appreciably. This should be taken into account in use of the photographic technique. If data from plots C-5 and C-10 were eliminated, the average transmission factor from the photographs would rise to 21.8%, which is much closer to the average value obtained from radiation measurements. Because of this good agreement, it appears reasonable to use calculated probabilities for radiation penetration, as calculated from hemispherical photographs, to estimate the fraction of total solar radiation above the canopy which will reach the forest floor.

Several advantages are evident for using canopy picture analysis over actual radiation measurements in studying the transmission properties of forest canopies. First, the cost of equipment is relatively small when taking fish-eye hemispherical canopy pictures, for only a special camera lens is

required. Expensive and reliable sensing and recording instruments are necessary for actual pyranometer measurements. Secondly, spatial variations in sampling errors under the forest canopy can be minimized by taking a large number of pictures at relatively small cost. To reach the same level of sampling error with pyranometer measurements, more sensing-recording equipment, or expensive "moving sensors" as suggested by Mukammal (1971) would be required. Fish-eye hemispherical pictures also reduce the need for frequent visits to the experimental plots in order to maintain radiation measurement equipment. This point is important whenever the research site is located in a relatively remote area.

Estimates of probabilities for diffuse radiation penetration from hemispherical canopy pictures taken at the experimental site are shown in Table 3. All data have been averaged over 12 plots for each block. L.s.d. values at the 5% probability level for comparisons of penetration probabilities before and after treatment on defoliated blocks (A and C) are also given in the table. Before defoliation, the four blocks had essentially the same probability of diffuse radiation penetration when the entire hemisphere was considered. Significant canopy opening following defoliation was evident for Block A, which changed from 21.2 to 28.1% penetration, and for Block C, which changed from 19.3 to 35.9% penetration. The more severe defoliation observed for Block C was probably due to differential crown structures and to differing stand conditions between the two stands.

Figures 6 and 7 provide plots of the probability of radiation penetration at different elevation angles both before and after defoliation. Probabilities were high for high elevation angles. In other words, most radiation penetration occurred near the zenith. This was particularly true for Block C after defoliation.

TABLE 3.--Average percent penetration of diffused radiation, as estimated from hemispherical canopy photographs

| | Elevation Angle (degrees) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-10 | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | 60-70 | 70-80 | 80-90 | Whole hemisphere |
| Block A (Pre-defoliation) | | 2.04 | 5.73 | 11.03 | 18.49 | 22.79 | 20.17 | 25.91 | 31.42 | 21.19 |
| S. dev. | | 0.72 | 2.60 | 3.76 | 6.26 | 6.44 | 7.44 | 10.48 | 9.64 | 5.7[illegible] |
| (Post defoliation) | 0.09 | 3.69 | 8.38 | 15.89 | 23.66 | 29.91 | 31.77 | 33.68 | 44.27 | 28.05 |
| S. dev. | 0.30 | 1.03 | 2.83 | 4.16 | 5.01 | 5.74 | 5.68 | 10.20 | 9.59 | 5.[illegible] |
| l.s.d. 0.05 level | 0.18 | 0.73 | 2.30 | 3.35 | 4.80 | 5.16 | 5.60 | 8.76 | 8.14 | 4.59 |
| Block B | 0.28 | 2.41 | 6.16 | 10.80 | 19.22 | 24.24 | 26.23 | 28.41 | 29.78 | 21.66 |
| S. dev. | 0.63 | 1.28 | 1.56 | 2.12 | 6.25 | 8.98 | 8.57 | 9.77 | 11.95 | 4.97 |
| Block C (Pre-defoliation) | | 0.09 | 3.04 | 10.24 | 16.84 | 21.48 | 24.61 | 24.91 | 27.24 | 19.29 |
| S. dev. | | 0.20 | 1.33 | 3.18 | 4.66 | 6.08 | 6.93 | 10.11 | 15.45 | 5.3[illegible] |
| (Post defoliation) | | 1.17 | 8.46 | 19.79 | 29.73 | 35.90 | 40.41 | 48.92 | 55.95 | 35.92 |
| S. dev. | | 0.51 | 2.08 | 4.84 | 4.97 | 4.60 | 7.99 | 16.70 | 26.83 | 7.66 |
| l. s. d. 0.05 level | | 0.32 | 1.48 | 3.47 | 4.08 | 4.56 | 6.33 | 11.69 | 18.54 | 5.60 |
| Block E | | 1.52 | 7.90 | 16.63 | 20.53 | 23.22 | 28.39 | 24.09 | 33.33 | 22.48 |
| S. dev. | | 1.46 | 4.41 | 6.80 | 6.07 | 5.56 | 6.49 | 4.91 | 22.10 | 3.94 |

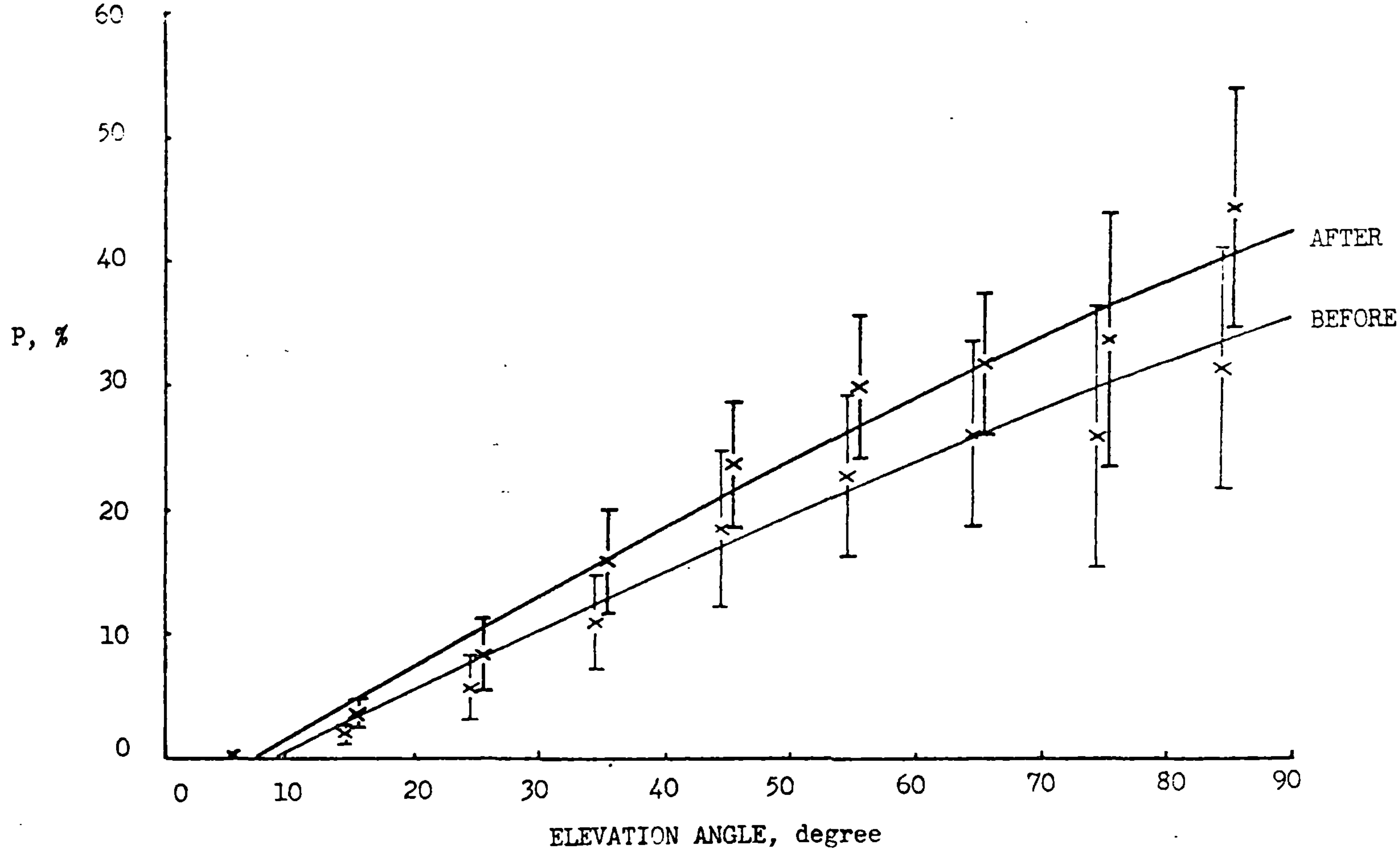



Fig. 6. AVERAGE PROBABILITY OF DIFFUSE RADIATION PENETRATION (P), INCLUDING STANDARD DEVIATIONS, AT DIFFERENT ELEVATION ANGLES FOR BLOCK A BEFORE AND AFTER DEFOLIATION.

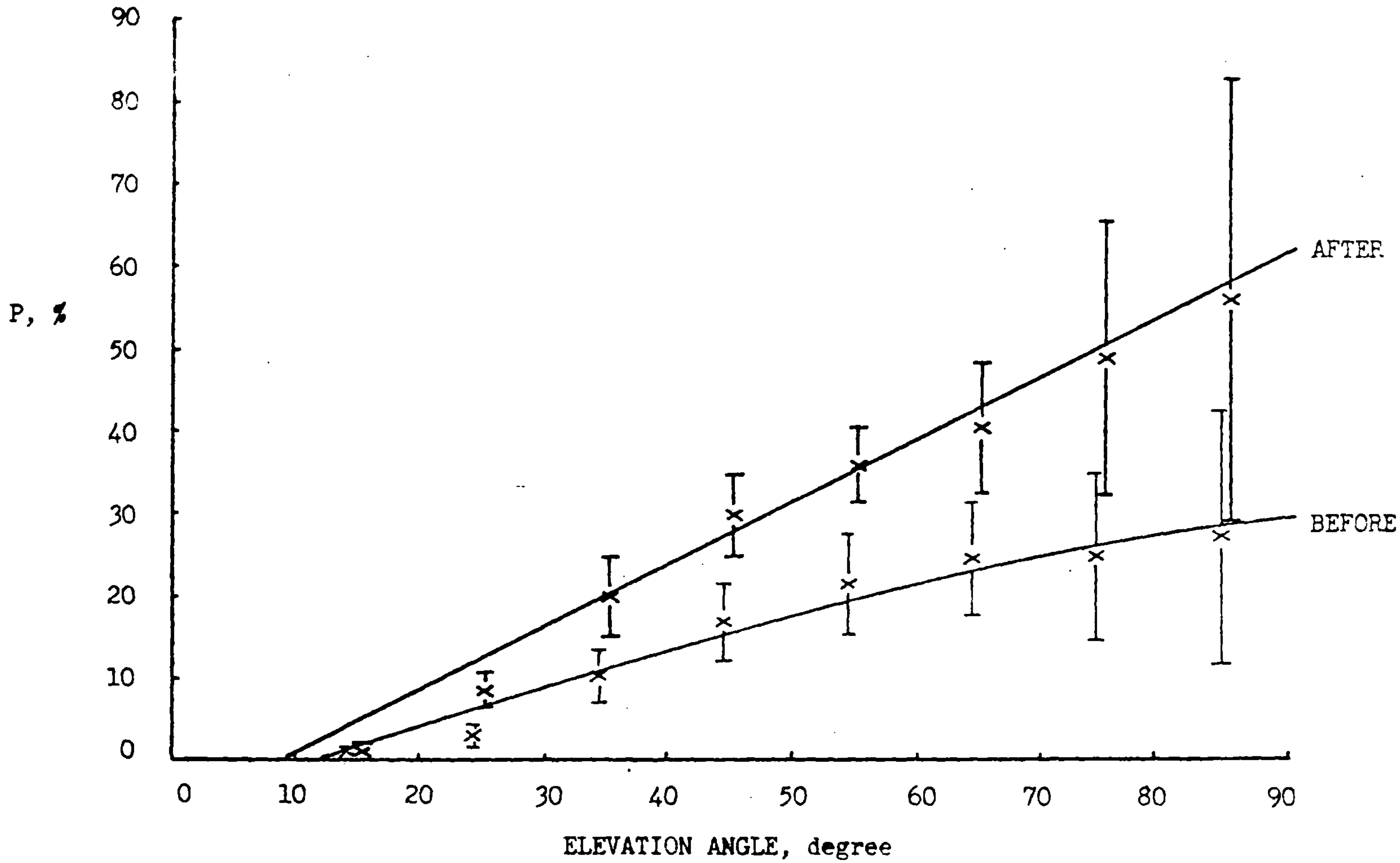



FIG. 7. AVERAGE PROBABILITY OF DIFFUSE RADIATION PENETRATION (P), INCLUDING STANDARD DEVIATIONS, AT DIFFERENT ELEVATION ANGLES FOR BLOCK C BEFORE AND AFTER DEFOLIATION.

Solar radiation reaching the forest floor can be partitioned into two components: that which is reflected back to the atmosphere and that which is absorbed by forest floor materials. The latter is further redistributed as heat (both sensible and latent) and as longwave radiation. The albedo (shortwave reflectivity) of the forest floor, which controls the amount of solar radiation absorbed, was measured on September 2, 1976, and on June 30, 1977. These data are presented in Table 4. The albedo immediately following defoliation appeared to be significantly higher for the defoliated blocks than for the control. This was attributed to the ground being covered with a layer of highly reflective, greenish-brown needles in the A anc C blocks, compared to the dark brown color of normal forest floor materials in Blocks B and E. The trend of decreased absorptivity of the forest floor following defoliation appears to be less than the trend of increased probability for radiation penetration. Thus, more solar radiation should be absorbed by the forest floor following defoliation. This conclusion can be demonstrated by assuming the total incoming solar radiation reaching the top of the canopy to be 600 $cal/cm^2/day$, which would be a typical midsummer value for the experimental site. Furthermore, the following values can be assumed for normal and defoliated stands, respectively:

| | Normal Stand | Defoliated Stand |
|---|---|---|
| % canopy opening | 21.5 | 28.0 |
| Radiation on the forest floor ($cal/cm^2/day$) | 600 x 0.215 = 129 | 600 x 0.28 = 168 |
| Albedo (%) | 7.0 | 16.0 |
| Radiation absorbed by the forest floor ($cal/cm^2/day$) | 129 x (1-0.07) = 120 | 168 x (1-0.16) = 141 |

Table 4. Average albedo (shortwave reflectivity) of forest floor in the four experimental blocks.

| Block | Mean Albedo (%) | Standard Deviation |
|---|---|---|
| | September 2, 1976 | |
| A | 15.9 | 1.6 |
| B | 6.4 | 0.8 |
| C | 17.1 | 1.9 |
| E | 8.7 | 1.1 |
| | June 30, 1977 | |
| A | 11.2 | 1.5 |
| B | 6.5 | 0.9 |
| C | 12.6 | 1.6 |
| E | 7.8 | 1.1 |

Thus, although the increased albedo of the defoliated stand lessens the effect of increased radiation reaching the forest floor, it does not completely offset it. After newly fallen needles age and darken in color, the albedo of the litter in the defoliated blocks should approach that of the control blocks. This should further increase the solar radiation absorbed by forest floor materials in the defoliated stand during the period before establishment of new needles in the canopy. This is evident by the overwinter change in albedo from September 2, 1976, to June 20, 1977.

In 1977 solar radiation was monitored on a continuous basis from May through October in order to determine both the peak and average levels of solar radiation reaching the top of the canopy. These values could also be used to determine if any relationship existed between radiation reaching the top of the canopy, changes in the radiation transmission characteristic of the canopy because of defoliation, and changes in air and soil temperature regimes at the experimental site.

Average changes in attenuation of solar radiation from the outer atmosphere to the forest floor, based on 10-day average values, are shown in Table 5. The attenuation coefficients are based on the hemispherical photograph data of Table 3. Based upon these calculations, defoliation should have allowed an average of 5,614 calories to reach each square centimeter of forest floor in Block A, with a corresponding figure of 13,479 calories for Block C, during the period May 1 to October 31, 1977. Using average forest floor albedo data obtained on June 30, 1977, 4,985 cal/cm$^2$ of additional energy would have been absorbed by the forest floor for sensible heating, evaporation, or longwave re-radiation in Block A following defoliation. The corresponding

Table 5. Attenuation of solar radiation from the outer atmosphere to the forest floor.

| Period | Ave. Pot. Radiation | Ave. Trans. Coef. | Trans. Coef. Range | Ave. Above Canopy Rad. | Average Sky Radiation Reaching Forest Floor: Predefoliation | | Average Sky Radiation Reaching Forest Floor: Postdefoliation | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Block A | Block C | Block A | Block C |
| 1977 | cal/cm$^2$/day | (%) | (%) | - - - - - - - - - - - cal/cm$^2$/day - - - - - - - - - - - - - | | | | |
| Apr. 11-20 | 769 | 46.5 | 25.5-73.0 | 358 | 76 | 69 | 100 | 129 |
| May 1-10 | 878 | 49.8 | 11.4-57.6 | 437 | 93 | 84 | 123 | 157 |
| 11-20 | 922 | 49.3 | 40.4-69.3 | 455 | 96 | 68 | 128 | 163 |
| 21-31 | 956 | 50.8 | 14.2-74.0 | 485 | 103 | 93 | 136 | 174 |
| June 1-10 | 982 | 56.9 | 22.0-72.1 | 559 | 118 | 108 | 157 | 201 |
| 11-20 | 994 | 61.1 | 39.7-74.8 | 607 | 129 | 117 | 170 | 218 |
| 21-30 | 995 | 66.1 | 47.7-71.3 | 658 | 139 | 127 | 184 | 236 |
| July 1-10 | 985 | 63.5 | 58.5-72.1 | 625 | 132 | 121 | 175 | 225 |
| 11-20 | 965 | 58.7 | 39.1-69.0 | 566 | 120 | 109 | 159 | 203 |
| 21-31 | 934 | 59.4 | 38.5-70.0 | 555 | 118 | 107 | 156 | 199 |

Table 5. Attenuation of solar radiation from the outer atmosphere to the forest floor (Continued)

| Period | Ave. Pot. Radiation | Ave. Trans. Coef. | Trans. Coef. Range | Ave. Above Canopy Rad. | Average Sky Radiation Reaching Forest Floor: Predefoliation Block A | Predefoliation Block C | Postdefoliation Block A | Postdefoliation Block C |
|---|---|---|---|---|---|---|---|---|
| 1977 | $cal/cm^2/day$ | (%) | (%) | $cal/cm^2/day$ | | | | |
| Aug. 1-10 | 890 | 62.6 | 42.8-68.8 | 557 | 118 | 107 | 156 | 200 |
| 11-20 | 842 | 64.6 | 39.4-67.6 | 544 | 115 | 105 | 153 | 195 |
| 21-31 | 787 | 41.8 | 21.2-69.6 | 329 | 70 | 63 | 92 | 118 |
| Sept. 1-10 | 720 | 43.1 | 44.9-68.3 | 310 | 66 | 60 | 87 | 111 |
| 11-20 | 656 | 44.2 | 8.3-66.0 | 290 | 61 | 56 | 81 | 104 |
| 21-30 | 589 | 42.4 | 12.4-67.4 | 250 | 53 | 48 | 70 | 90 |
| Oct. 1-10 | 522 | 55.4 | 27.5-69.4 | 289 | 61 | 56 | 81 | 104 |
| 11-20 | 457 | 60.5 | 45.5-65.6 | 276 | 58 | 53 | 77 | 99 |
| 21-31 | 396 | 40.3 | 17.9-61.5 | 160 | 34 | 31 | 45 | 57 |
| Nov. 1-10 | 336 | 35.4 | 3.8-56.7 | 119 | 25 | 23 | 33 | 43 |

increase for Block C would have been 11,781 cal/cm$^2$, because of an increased defoliation level. It appears that defoliation provides considerable opportunity for increased soil temperatures and subsequent influence on forest floor biologic activities. The potential is particularly great for Block C.

## Air and Soil Temperature Regimes

Diurnal air and soil temperature regimes were monitored before defoliation in order to determine the temperature relationships between the control blocks, B and E, and those blocks scheduled for defoliation, A and C. Although insufficient data were collected to permit a statistical evaluation because of the non-availability of continuous monitoring equipment, all temperature sensors in the blocks scheduled for defoliation, except for those at the 0-, 2.5- and 7.5-cm soil depths in Block A, corresponded to temperatures in the respective control blocks. Because of different forest floor conditions and also because of possible placement error or damage after installation, the 0-cm depth sensor in Block A ranged from 0.3 to 0.7$^{o}$ C colder than in the corresponding control block, B. Similarly, Block A sensors at the 2.5-cm soil depth ranged from 0.5 to 2.0$^{o}$ C colder, and at the 7.5-cm depth, 0.1 to 1.0 $^{o}$C colder, than for Block B. This difference in temperature was minimal at night and maximum during the warmest part of the day.

The influence of defoliation on air and soil temperature regimes during 1976 can be demonstrated from temperature data for three 2-day periods. These data are presented in both Tables 8 and 9 and in Figures 6 and 7. The first period represents pre-defoliation, where both the treatment and control blocks retained normal stand structures. The July 1976 period represents partial defoliation, when the forest floor was covered with a thin layer of newly fallen needles in the treatment block. The final period represents a time of extensive defoliation, with a thick needle layer overlying the original forest floor.

TABLE 6. DIURNAL AIR AND SOIL TEMPERATURE REGIMES FOR BLOCKS A AND B IN 1976.

| | Block A | | Block B | |
|---|---|---|---|---|
| Date/Depth | Mean(C) | Min.-Max.(C) | Mean(C) | Min.-Max.(C) |
| June 26, 1976 | | | | |
| 1 m | 11.8 | 5.8--18.4 | 12.0 | 5.8--19.1 |
| 0 cm | 9.7 | 7.2--13.2 | 10.2 | 7.4--13.8 |
| -2.5 cm | 8.5 | 7.8-- 9.3 | 9.3 | 7.9--10.9 |
| -7.5 cm | 8.3 | 7.8-- 8.7 | 8.8 | 7.9-- 9.8 |
| -30 cm | 8.0 | 7.6-- 8.3 | 8.1 | 7.9-- 8.2 |
| July 27, 1976 | | | | |
| 1 m | 15.4 | 6.0--23.3 | 15.2 | 6.0--23.5 |
| 0 cm | 13.4 | 10.0--16.1 | 14.6 | 9.3--18.8 |
| -2.5 cm | 12.6 | 11.8--13.2 | 12.8 | 11.4--13.2 |
| -7.5 cm | 12.1 | 11.7--12.6 | 12.3 | 11.5--12.9 |
| -30 cm | 11.5 | 11.3--11.8 | 11.6 | 11.3--11.9 |
| August 21, 1976 | | | | |
| 1 m | 12.3 | 4.4--20.0 | 11.9 | 4.4--19.1 |
| 0 cm | 11.3 | 9.0--13.5 | 12.0 | 8.3--15.3 |
| -2.5 cm | 12.1 | 11.1--13.0 | 11.2 | 9.4--13.0 |
| -7.5 cm | 11.8 | 11.3--12.1 | 11.7 | 11.1--12.4 |
| -30 cm | 11.6 | 11.4--11.9 | 11.5 | 11.3--11.9 |

| | Block A | | Block B | |
|---|---|---|---|---|
| Date/Depth | Mean(C) | Min.-Max.(C) | Mean(C) | Min.-Max.(C) |
| June 29, 1976 | | | | |
| 1 m | 15.2 | 10.9--20.1 | 15.2 | 10.5-20.1 |
| 0 cm | 12.6 | 10.8--14.6 | 12.9 | 11.2--14.7 |
| -2.5 cm | 10.3 | 9.7--10.7 | 11.5 | 10.7--12.1 |
| -7.5 cm | 9.9 | 9.5--10.4 | 10.8 | 9.7--11.3 |
| -30 cm | 8.5 | 7.9-- 9.0 | 8.6 | 7.9-- 9.1 |
| July 29, 1976 | | | | |
| 1 m | 18.3 | 16.1--21.3 | 18.3 | 16.1--21.2 |
| 0 cm | 14.9 | 14.1--16.1 | 16.4 | 15.2--18.6 |
| -2.5 cm | 13.3 | 13.0--13.5 | 13.9 | 13.5--14.4 |
| -7.5 cm | 12.6 | 12.0--13.0 | 12.9 | 12.5--13.4 |
| -30 cm | 11.9 | 11.6--12.3 | 11.9 | 11.6--12.5 |
| August 23, 1976 | | | | |
| 1 m | 17.3 | 11.8--23.9 | 16.8 | 11.6--22.5 |
| 0 cm | 13.1 | 11.3--15.2 | 14.5 | 12.2--17.6 |
| -2.5 cm | 13.2 | 12.1--14.2 | 12.5 | 11.[illegible]--13.8 |
| -7.5 cm | 12.6 | 12.1--13.0 | 13.0 | 12.2--13.8 |
| -30 cm | 11.6 | 11.4--12.2 | 11.4 | 11.0--11.6 |

TABLE 7. Diurnal soil temperature regimes for Blocks C and E in 1976.

| | Block C | | Block E | | | Block C | | Block E | |
|---|---|---|---|---|---|---|---|---|---|
| Date/Depth | Mean(C) | Min.-Max.(C) | Mean(C) | Min.-Max.(C) | Date/Depth | Mean(C) | Min.-Max.(C) | Mean(C) | Min.-Max.(C) |
| June 25, 1976 | | | | | June 26, 1976 | | | | |
| 0 cm | 7.2 | 5.2--10.0 | 7.7 | 6.0--11.0 | 0 cm | 9.2 | 6.1--13.0 | 9.4 | 6.4--14.5 |
| -7.5 cm | 8.0 | 7.5-- 8.5 | 8.2 | 8.0-- 8.4 | -7.5 cm | 8.1 | 7.2-- 9.4 | 8.2 | 7.5-- 9.1 |
| -30 cm | 7.9 | 7.6-- 8.2 | 8.1 | 8.0-- 8.2 | -30 cm | 7.4 | 7.2-- 7.8 | 7.8 | 7.5-- 8.0 |
| July 28, 1976 | | | | | July 29, 1976 | | | | |
| 0 cm | 14.9 | 9.8--22.5 | 14.8 | 9.4--21.0 | 0 cm | 15.5 | 13.9--20.2 | 15.7 | 14.5--18.2 |
| -7.5 cm | 12.4 | 11.4--13.5 | 12.3 | 11.7--13.0 | -7.5 cm | 12.9 | 12.0--13.2 | 12.8 | 12.5--13.0 |
| -30 cm | 11.1 | 11.0--11.2 | 11.4 | 11.2--11.5 | -30 cm | 11.1 | 11.1--11.2 | 11.4 | 11.3--11.5 |
| August 19, 1976 | | | | | August 20, 1976 | | | | |
| 0 cm | 11.5 | 10.0--13.5 | 10.9 | 9.6--12.4 | 0 cm | 12.3 | 10.6--15.3 | 11.6 | 10.1--14.2 |
| -7.5 cm | 11.9 | 11.5--12.3 | 11.6 | 11.2--12.0 | -7.5 cm | 11.9 | 11.2--13.0 | 11.4 | 10.0--11.9 |
| -30 cm | 11.6 | 11.5--11.8 | 11.4 | 11.2--11.7 | -30 cm | 11.3 | 11.1--11.6 | 11.1 | 11.0--11.2 |

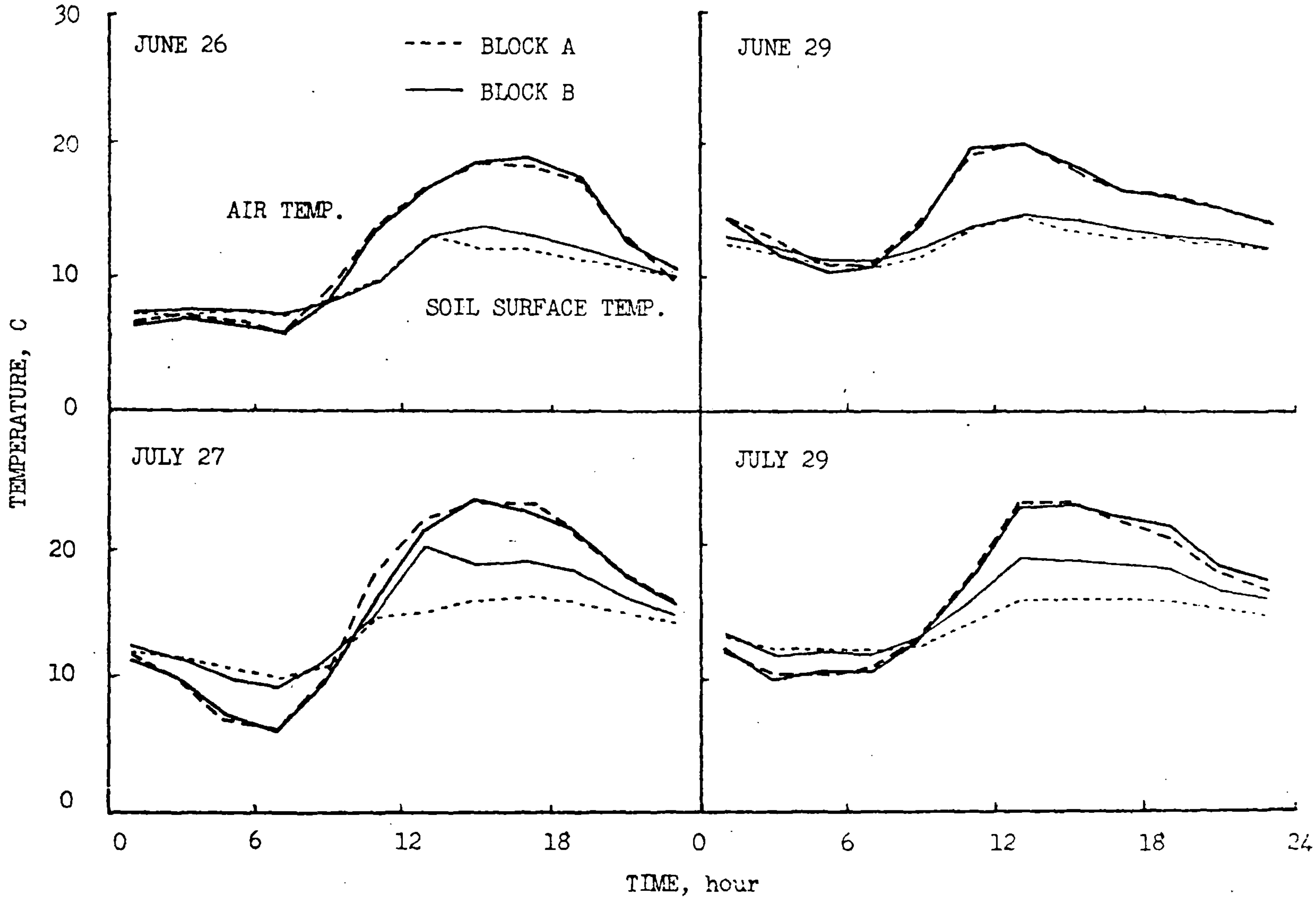



FIG. 8. DIURNAL AIR TEMPERATURES AT 1-M HEIGHT, AND SOIL SURFACE TEMPERATURES (0-CM DEPTH) FOR BLOCKS A AND B.

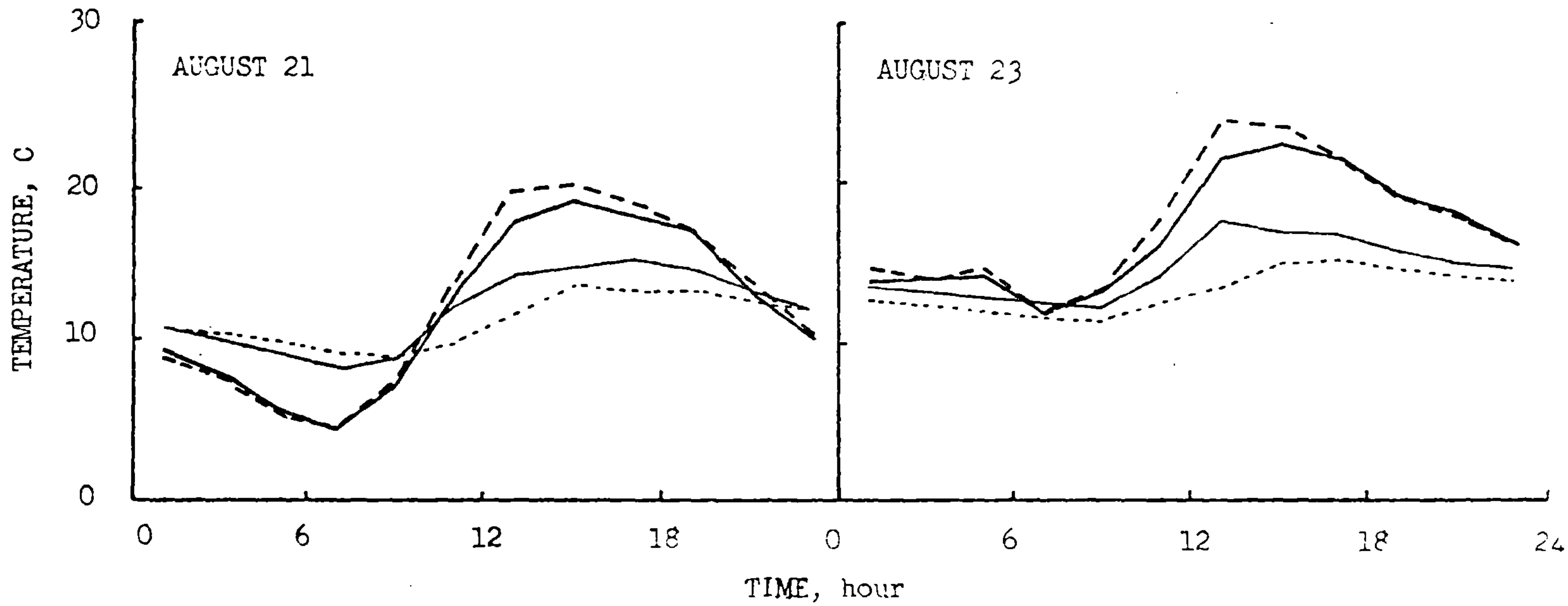



FIG. 8. CONTINUED.

For the predefoliation period illustrated here (June 26 and 29), essentially the same air temperatures at the 1-m height were observed both for Blocks and and B. As pointed our earlier, slightly cooler temperatures at the litter-soil interface (0-cm depth) were observed for Block A from the readings for 1500 and 1700 hours. Soil temperatures at the 2.5- and 7.5-cm depths were also slightly higher in control Block B, both with respect to daily mean and maximum temperatures. Minimum temperature at the 2.5-cm depth on June 29 was higher by $1^{o}$ C for Block B than for Block A.

During the second stage, in late July, noticeable temperature differences at the 0-cm depth were observed between Blocks A and B. The minimum temperature at the 0-cm depth was about $1^{o}$ C higher for Block A, whereas the maximum temperature was about $2.5^{o}$ C lower. The daily mean temperatures at the litter-soil interface were $1.2^{o}$ C and $1.5^{o}$ C cooler in the defoliated block (Block A) for July 27 and 29, respectively. Daily temperature regimes at the 2.5-, 7.5-, and 30-cm soil depths were essentially the same for both blocks on July 27. Slightly warmer daily mean and maximum temperatures for the 2.5-cm depth appeared in control Block B on July 29.

Diurnal temperature fluctuations at the litter-soil interface (Fig. 8 showed that the heat flux did not appear to be large across the litter layer in defoliated Block A. The increased resistance to heat transfer was most likely caused by the thin layer of newly fallen needles resulting from the first Paraquat spray. No difference in air temperatures between blocks was observed during this second sampling period.

Following extensive needle fall after the second defoliation treatment, the data from August 21 and 23 showed daily mean temperatures at 1-m above the soil surface to be 0.4 to 0.5$^{o}$ C warmer for the defoliated block (Block A). No differences were observed in minimum temperatures at this height, whereas the maximum temperatures were 0.9 and 1.4$^{o}$ C higher for Block A than for Block B on August 21 and 23, respectively. Figure 8 also shows that the greatest temperature differences after defoliation appear to have occurred during the daytime hours. The warmer daytime air temperatures in defoliated Block A were most likely due to increased canopy opening, which offered less canopy resistance to solar radiation penetration or to downward heat flux from the canopy surface.

Due to the colder temperatures observed for Block A at the 0-, 2.5-, and 7.5-cm soil depths before treatment, interpretation of the effects of defoliation on the temperature regimes at these depths is difficult. Generally, the mean temperature at the 0-cm depth was noticeably lower in the defoliated plot than with control. Differences in mean temperature on August 21 and 23 were 0.7 and 1.4$^{o}$ C, whereas in the pred-defoliation period the differences were only 0.5 and 0.3$^{o}$ C, respectively. Although temperatures were colder for the defoliated plot at the 0-cm depth, mean temperatures appeared to be warmer for this block at the 2.5- and 7.5-cm depths. Such data appear to be contradictory. However, due to differences in heat capacity between the forest floor and the underlying mineral soil, and because of the shorter day length at this time of year, such conditions could have existed. The data suggest that the true effect of defoliation on soil temperature regimes can only be diagnosed by fairly complete analyses of data from early spring to late fall. Use of data covering only a 2-day period in the fall appears insufficient.

Data from Blocks C and E showed somewhat different temperature regimes than for Blocks A and B. Figure 9 shows the diurnal temperature fluctuations at the 0-cm depth for three pairs of days representing the three different canopy structure stages discussed above. Daily mean, maximum and minimum temperatures at different soil depths for Blocks C and E are shown in Table 7.

Higher temperatures at the 0-cm depth were obtained for Block E than for Block C on June 25 and 26. On July 27 and 29, one month after the first spray, temperature readings at the 0-cm depth showed the defoliated block (Block C) to be warmer during the afternoon hours. Daily mean temperatures at the 0-cm depth were the same for both defoliated and control blocks on July 28 and 29. Data from August 19 and 20 showed the defoliated block to have higher daily mean, maximum and minimum temperatures at the 0-cm and 7.5-cm soil depths. No temperature differences between Blocks C and E were observed at the 30-cm depth.

In contrast to Block A, the temperature of Block C near the soil surface appeared to be warmer than for corresponding depths from the reference block following defoliation. During the daytime hours, increased solar radiation inputs to the forest floor following defoliation appear to have overcome any mulching effect brought about by the layer of newly fallen needles. During the evening hours, the mulching effect seems to have reduced the heat loss from soil to air. Thus, the soil temperature in the defoliated block (Block C) remained warmer than in the control block (Block E). The differential temperature regimes between Blocks A and C following defoliation were most likely due to the different extents of canopy opening.

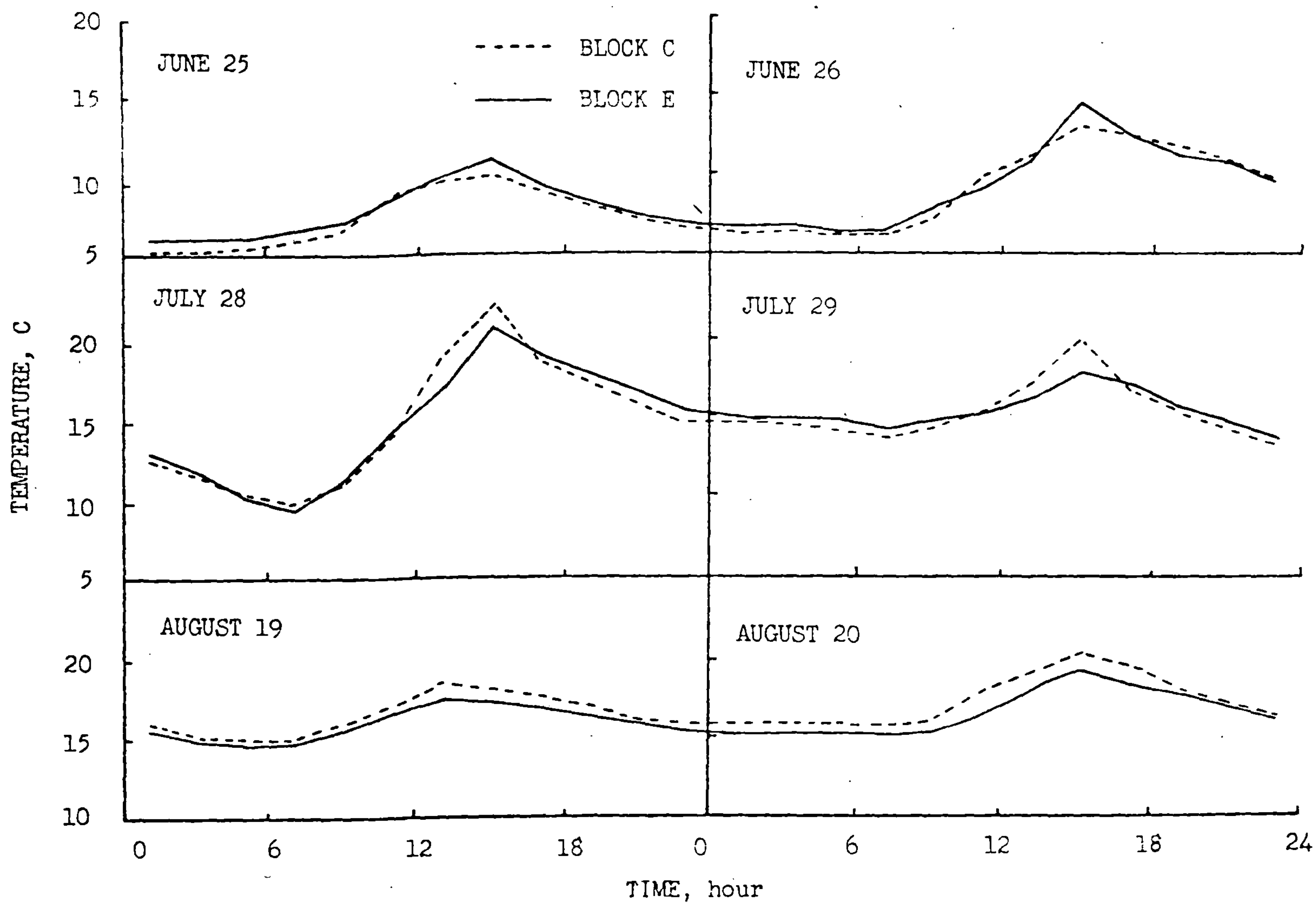



FIG. 9. DIURNAL TEMPERATURE FLUCTUATIONS AT THE 0-CM DEPTH FOR BLOCKS C AND E.

Because the 1976 data demonstrated the necessity for longterm measurement of temperatures in order to determine the real effects of defoliation, continuous monitoring of all sensors was attempted in 1977. Due to a few equipment malfunctions, data were not continuously available from the Block A-B replication for the entire year. Such data were available for the Block C and E replication.

To illustrate the treatment effect, we have chosen representative days for presentation from throughout the year. Although similar to the approach used for 1976, the periods portrayed for 1977 could be selected on the basis of their degree of representability because of this fairly continuous data base rather than the virtually "blind" selection of sampling dates for 1976. On each of these representative days, weather monitoring indicated that conditions were quite steady, i.e. that no storm fronts were passing, that cloud cover was at a minimum, and that a general warming trend was occurring. Some soil temperature data were even available from February when the normal snow cover melted due to local drought conditions. In March snow cover returned so reliable soil temperature data became unavailable because of difficulty in servicing the equipment shelters until early April. Mean minimum and maximum temperatures at each level sampled on the representative days are shown in Tables 8 through 14. Diurnal temperature differences between treatment and control are illustrated in Figures 10 through 23.

Table 8. Air temperatures during 1977 at the 100-cm level.

| Date | Block B (Control) | | Block A (Defoliated) | | Δ Mean |
|---|---|---|---|---|---|
| | Mean (°C) | Min-Max (°C) | Mean (°C) | Min-Max (°C) | °C |
| May 19 | 10.6 | 4.7-15.0 | 10.9 | 5.1-15.9 | 0.3 |
| June 24 | 19.5 | 11.2-27.0 | 19.7 | 11.0-28.2 | 0.2 |
| July 1 | 17.4 | 10.7-23.7 | 17.6 | 10.8-25.8 | 0.2 |
| July 13 | 18.1 | 14.9-24.2 | 18.4 | 14.8-25.3 | 0.3 |
| | Block E | | Block C | | |
| Feb. 19 | 1.8 | -1.5-7.3 | 1.5 | -1.4-6.3 | -0.3 |
| April 1 | 5.2 | 1.5-8.6 | 5.0 | 1.4-9.4 | -0.2 |
| April 28 | 9.8 | 0.1-18.8 | 9.8 | 0.0-19.1 | 0.0 |
| May 19 | 8.9 | 5.6-13.4 | 9.1 | 5.6-13.7 | 0.2 |
| May 28 | 6.6 | 1.7-11.9 | 6.8 | 1.5-12.4 | 0.2 |
| June 14 | 14.7 | 7.3-21.2 | 15.1 | 7.0-23.3 | 0.4 |
| June 24 | 18.6 | 11.0-25.7 | 19.2 | 10.6-26.9 | 0.6 |
| July 1 | 16.8 | 11.5-23.8 | 17.0 | 11.0-25.2 | 0.2 |
| July 13 | 14.4 | 10.1-20.3 | 14.5 | 10.0-20.9 | 0.1 |
| July 30 | 18.0 | 8.4-26.6 | 18.3 | 8.2-27.7 | 0.3 |
| Aug. 12 | 22.9 | 12.5-32.7 | 23.2 | 12.1-33.5 | 0.3 |
| Sept. 12 | 14.7 | 6.6-23.0 | 14.7 | 6.4-24.2 | 0.0 |
| Oct. 14 | 5.6 | 0.3-14.0 | 5.4 | 0.2-13.3 | -0.2 |
| Nov. 12 | 0.7 | -0.5-2.1 | 0.5 | -0.5-1.8 | -0.2 |

Table 9. Air temperatures during 1977 at the 10-cm level.

| Date | Block B (Control) | | Block A (Defoliated) | | Δ Mean |
|---|---|---|---|---|---|
| | Mean (°C) | Min-Max (°C) | Mean (°C) | Min-Max (°C) | °C |
| May 19 | 10.7 | 5.1-15.8 | 11.3 | 5.2-19.3 | 0.6 |
| June 24 | 19.5 | 11.6-27.6 | 20.2 | 11.1-31.1 | 0.7 |
| July 1 | 17.7 | 11.2-25.5 | 18.2 | 11.1-28.4 | 0.5 |
| July 13 | 18.2 | 13.2-24.6 | 18.7 | 12.7-27.1 | 0.5 |
| | Block E | | Block C | | |
| Feb. 19 | 1.3 | -0.7-5.8 | 0.4 | -0.6-2.0 | -0.9 |
| April 1 | 4.7 | 2.3-8.2 | 4.3 | 1.7-8.7 | -0.9 |
| April 28 | 9.5 | 0.3-17.8 | 9.8 | 0.2-19.8 | 0.3 |
| May 19 | 8.8 | 5.6-14.7 | 9.3 | 5.3-15.4 | 0.5 |
| May 28 | 6.7 | 1.9-13.5 | 7.1 | 1.5-14.2 | 0.4 |
| June 14 | 14.3 | 7.3-21.8 | 15.1 | 7.0-24.8 | 0.8 |
| June 24 | 18.6 | 10.8-25.4 | 19.7 | 10.6-29.4 | 1.1 |
| July 1 | 17.0 | 11.6-25.5 | 17.5 | 11.0-27.8 | 0.5 |
| July 13 | 14.6 | 10.1-21.6 | 14.8 | 9.6-22.8 | 0.2 |
| July 30 | 18.0 | 8.5-27.6 | 18.3 | 8.3-29.7 | 0.3 |
| Aug. 12 | 22.7 | 12.5-32.7 | 23.0 | 12.3-35.4 | 0.3 |
| Sept. 12 | 14.3 | 6.7-21.8 | 14.5 | 6.5-24.5 | 0.2 |
| Oct. 14 | 5.3 | 0.7-14.0 | 5.0 | 1.0-13.3 | -0.3 |
| Nov. 12 | 0.4 | -0.5-1.2 | 0.2 | -0.3-0.7 | -0.2 |

Table 10. Soil temperatures during 1977 at the mineral soil litter interface (0 cm).

| Date | Block B (Control) | | Block A (Defoliated) | | Δ Mean |
|---|---|---|---|---|---|
| | Mean (°C) | Min-Max (°C) | Mean (°C) | Min-Max (°C) | |
| May 19 | 7.7 | 6.1-10.2 | 8.2 | 6.7-10.2 | 0.5 |
| June 24 | 14.8 | 11.9-18.2 | 14.1 | 11.8-16.5 | -0.7 |
| July 1 | 14.7 | 12.6-17.8 | 14.3 | 12.5-17.3 | -0.4 |
| July 13 | 14.5 | 12.2-17.1 | 14.0 | 12.0-16.7 | -0.5 |
| | Block E | | Block C | | |
| Feb. 19 | -0.1 | -0.2-0.0 | -0.1 | -0.2--0.1 | 0.0 |
| April 1 | 2.0 | 1.0-3.6 | 3.1 | 1.8-5.4 | 1.1 |
| April 28 | 7.2 | 3.4-10.9 | 7.1 | 4.5-9.9 | -0.1 |
| May 19 | 6.9 | 5.4-9.5 | 7.5 | 5.8-11.1 | 0.6 |
| May 28 | 6.1 | 4.3-9.1 | 7.4 | 5.4-11.2 | 1.3 |
| June 14 | 11.9 | 9.4-14.8 | 12.5 | 10.0-16.5 | 0.6 |
| June 24 | 14.8 | 11.8-20.0 | 15.4 | 11.9-22.4 | 0.6 |
| July 1 | 15.1 | 12.4-20.8 | 19.0 | 12.6-20.8 | 3.9 |
| July 13 | 13.1 | 10.5-19.1 | 17.1 | 10.6-17.8 | 4.0 |
| July 30 | 15.5 | 11.0-20.4 | 15.0 | 11.5-21.0 | -0.5 |
| Aug. 12 | 19.8 | 14.8-25.5 | 18.2 | 14.3-25.5 | -1.6 |
| Sept. 12 | 13.0 | 10.1-15.6 | 12.9 | 10.4-16.4 | -0.1 |
| Oct. 14 | 5.7 | 2.9-8.5 | 5.8 | 3.4-8.5 | 0.1 |
| Nov. 12 | 1.2 | 0.8-1.4 | 0.9 | 0.9-1.0 | -0.3 |

Table 11. Soil temperatures during 1977 at the 2.5-cm depth.

| Date | Block B (Control) | | Block A (Defoliated) | | Δ Mean |
|---|---|---|---|---|---|
| | Mean (°C) | Min-Max (°C) | Mean (°C) | Min-Max (°C) | °C |
| May 19 | 7.6 | 6.3-8.9 | 7.7 | 7.0-8.7 | 0.1 |
| June 24 | 14.1 | 12.0-16.1 | 13.5 | 12.2-14.7 | -0.6 |
| July 1 | 14.5 | 12.9-16.6 | 13.7 | 12.7-14.8 | -0.7 |
| July 13 | 14.0 | 12.1-16.6 | 12.9 | 11.7-14.8 | -1.1 |
| | Block E | | Block C | | |
| Feb. 19 | -0.1 | | | | |
| April 1 | 1.5 | 0.9-2.2 | 2.9 | 1.9-4.3 | 1.4 |
| April 28 | 6.3 | 4.9-7.7 | 6.7 | 5.1-8.0 | 0.4 |
| May 19 | 6.5 | 5.7-7.4 | 7.3 | 6.1-9.0 | 0.8 |
| May 28 | 6.1 | 5.2-7.1 | 7.4 | 5.9-9.2 | 1.3 |
| June 14 | 11.3 | 9.9-12.7 | 12.3 | 10.4-14.6 | 1.0 |
| June 24 | 13.2 | 11.6-14.8 | 14.2 | 12.1-16.9 | 1.0 |
| July 1 | 13.6 | 12.5-15.5 | 14.1 | 12.6-16.5 | 0.5 |
| July 13 | 11.8 | 10.6-13.8 | 12.3 | 10.7-14.9 | 0.5 |
| July 30 | 14.1 | 12.2-16.2 | 14.2 | 12.1-16.6 | 0.1 |
| Aug. 12 | 17.3 | 15.1-19.3 | 17.1 | 14.7-20.2 | -0.2 |
| Sept. 12 | 12.6 | 10.9-14.2 | 12.9 | 10.9-15.0 | 0.3 |
| Oct. 14 | 6.1 | 4.5-7.5 | 5.8 | 4.4-7.2 | -0.3 |
| Nov. 12 | 1.6 | 1.5-1.7 | 1.3 | 1.3-1.4 | -0.3 |

Table 12. Soil temperatures during 1977 at the 7.5-cm depth.

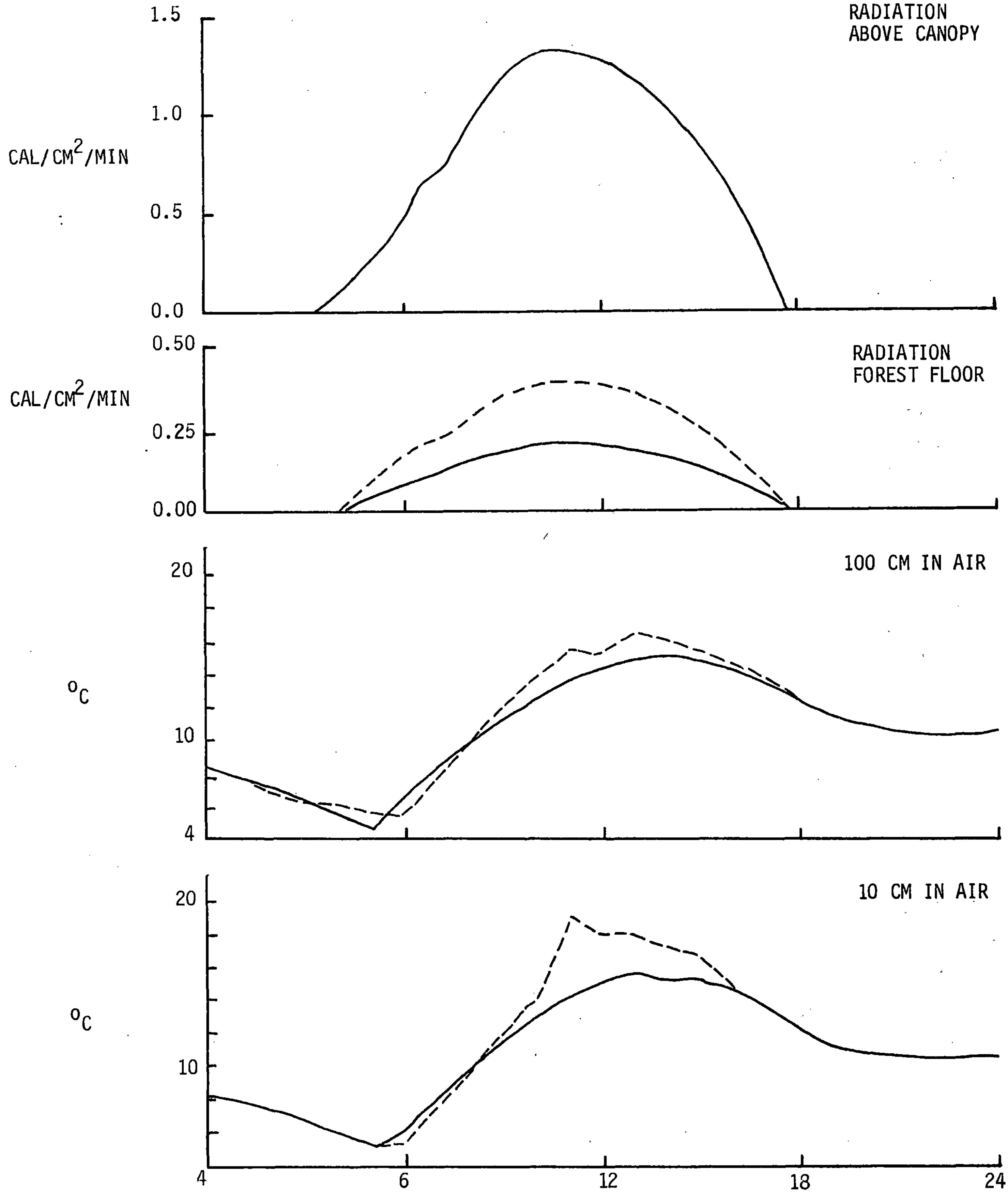
| Date | Block B (Control) | | Block A (Defoliated) | | Δ Mean |
|---|---|---|---|---|---|
| | Mean (°C) | Min-Max (°C) | Mean (°C) | Min-Max (°C) | °C |
| May 19 | 6.9 | 6.4-7.4 | 7.3 | 6.9-7.7 | 0.4 |
| June 24 | 12.8 | 12.0-13.8 | 13.1 | 11.9-13.2 | 0.3 |
| July 1 | 13.4 | 12.8-14.0 | 12.9 | 12.4-13.3 | -0.5 |
| July 13 | 12.5 | 11.8-13.4 | 12.1 | 11.6-12.6 | -0.4 |
| | Block E | | Block C | | |
| Feb. 19 | | | | | |
| April 1 | 0.9 | 0.5-1.3 | 2.5 | 2.1-3.1 | 1.6 |
| April 28 | 5.9 | 5.1-6.7 | 6.1 | 5.2-6.8 | 0.2 |
| May 19 | 6.2 | 5.7-6.7 | 6.9 | 6.3-7.8 | 0.7 |
| May 28 | 6.1 | 5.6-6.7 | 7.1 | 6.4-7.9 | 1.0 |
| June 14 | 10.8 | 10.1-11.6 | 11.6 | 10.6-12.6 | 0.8 |
| June 24 | 12.4 | 11.6-13.3 | 13.3 | 12.2-14.5 | 0.9 |
| July 1 | 13.0 | 12.5-13.6 | 13.3 | 12.5-13.8 | 0.3 |
| July 13 | 11.4 | 10.6-12.2 | 11.9 | 11.0-12.8 | 0.5 |
| July 30 | 13.6 | 12.6-14.6 | 13.7 | 12.7-14.7 | 0.1 |
| Aug. 12 | 16.3 | 15.3-17.3 | 16.1 | 14.9-17.1 | -0.2 |
| Sept. 12 | 12.4 | 11.4-13.3 | 12.6 | 11.6-13.7 | 0.2 |
| Oct. 14 | 6.4 | 5.6-7.0 | 6.3 | 5.6-6.8 | -0.1 |
| Nov. 12 | 1.8 | 1.8-2.0 | 1.7 | 1.6-1.8 | -0.1 |

Table 13. Soil temperatures during 1977 at the 15-cm depth.

| Date | Block B (Control) | | Block A (Defoliated) | | Δ Mean |
|---|---|---|---|---|---|
| | Mean ($^oC$) | Min-Max ($^oC$) | Mean ($^oC$) | Min-Max ($^oC$) | $^oC$ |
| May 19 | 6.6 | 6.3-7.0 | 7.2 | 6.9-7.6 | 0.6 |
| June 24 | 12.3 | 11.7-12.9 | 12.5 | 12.1-13.1 | 0.3 |
| July 1 | 12.9 | 12.5-13.1 | 12.9 | 12.4-13.3 | 0.0 |
| July 13 | 11.9 | 10.9-12.5 | 12.0 | 11.1-12.6 | 0.1 |
| | Block E | | Block C | | |
| Feb. 19 | -0.1 | -0.1-0.0 | 0.2 | 0.1-0.3 | -0.3 |
| April 1 | 0.8 | 0.2-1.1 | 2.3 | 2.1-2.8 | 1.5 |
| April 28 | 5.5 | 4.7-6.1 | 5.7 | 4.9-6.3 | 0.2 |
| May 19 | 6.0 | 5.6-6.5 | 6.7 | 6.3-7.2 | 0.7 |
| May 28 | 6.1 | 5.6-6.4 | 7.1 | 6.6-7.6 | 1.0 |
| June 14 | 10.6 | 10.0-11.1 | 11.2 | 10.6-11.9 | 0.6 |
| June 24 | 12.1 | 11.6-13.0 | 12.8 | 11.7-13.7 | 0.7 |
| July 1 | 12.7 | 12.2-13.3 | 13.1 | 12.5-13.7 | 0.4 |
| July 13 | 11.8 | 10.6-11.8 | 11.7 | 11.1-12.2 | -0.1 |
| July 30 | 13.3 | 12.6-14.1 | 13.5 | 12.8-14.1 | 0.2 |
| Aug. 12 | 15.8 | 15.1-16.6 | 15.7 | 14.9-16.3 | -0.1 |
| Sept. 12 | 12.4 | 11.7-12.9 | 12.4 | 11.7-13.1 | 0.0 |
| Oct. 14 | 6.9 | 5.9-10.4 | 6.6 | 6.0-7.2 | -0.3 |
| Nov. 12 | 2.3 | 2.1-2.5 | 1.9 | 1.9-2.0 | -0.4 |

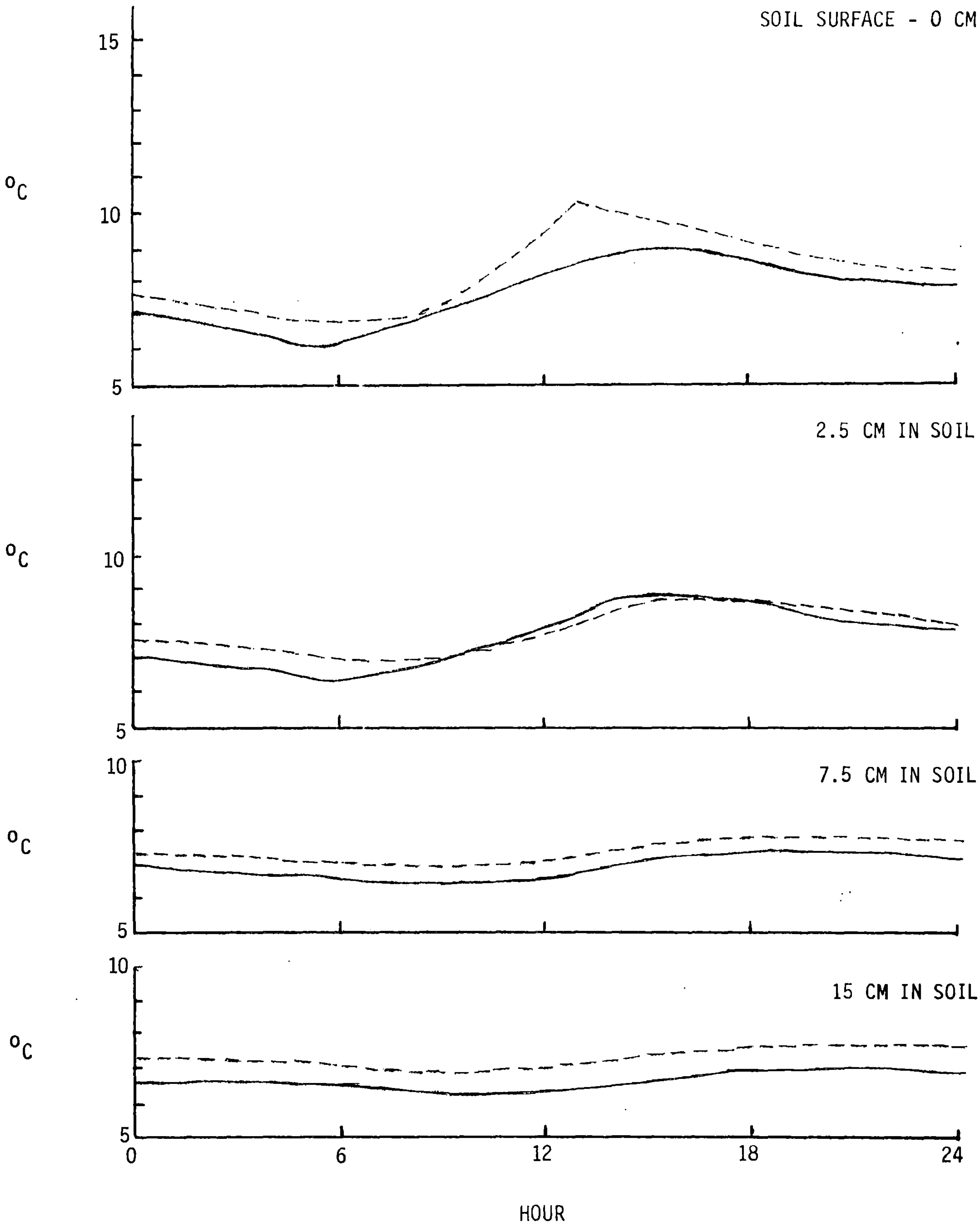
Table 14. Soil temperatures during 1977 at the 30-cm depth.

| Date | Block B (Control) | | Block A (Defoliated) | | Δ Mean |
|---|---|---|---|---|---|
| | Mean (°C) | Min-Max (°C) | Mean (°C) | Min-Max (°C) | °C |
| May 19 | 6.0 | 5.8-6.1 | 6.6 | 6.5-6.7 | 0.6 |
| June 14 | 11.1 | 10.9-11.3 | 11.3 | 11.2-11.5 | 0.2 |
| July 1 | 11.7 | 11.5-11.8 | 11.7 | 11.6-11.9 | 0.0 |
| July 13 | 11.2 | 10.9-11.3 | 11.2 | 11.1-11.3 | 0.0 |
| | Block E | | Block C | | |
| Feb. 19 | 0.3 | 0.3-0.4 | 0.4 | 0.3-0.5 | 0.1 |
| April 1 | 0.8 | 0.7-1.0 | 2.1 | 1.9-2.5 | 1.3 |
| April 28 | 4.8 | 4.1-5.1 | 4.9 | 4.1-5.6 | 0.1 |
| May 19 | 5.7 | 5.6-5.8 | 6.2 | 6.1-6.4 | 0.5 |
| May 28 | 6.1 | 5.9-6.8 | 6.9 | 6.7-7.0 | 0.8 |
| June 14 | 9.6 | 9.4-9.8 | 10.1 | 10.0-10.3 | 0.5 |
| June 24 | 11.0 | 10.9-11.2 | 11.6 | 11.5-11.9 | 0.6 |
| July 1 | 11.5 | 11.3-11.7 | 12.0 | 11.8-12.2 | 0.5 |
| July 13 | 10.7 | 10.5-10.9 | 11.2 | 11.0-11.3 | -0.5 |
| July 30 | 12.7 | 12.5-12.9 | 12.9 | 12.6-13.1 | 0.2 |
| Aug. 12 | 14.6 | 14.4-14.9 | 14.4 | 14.2-14.6 | -0.2 |
| Sept. 12 | 11.7 | 11.5-12.0 | 12.0 | 11.8-12.2 | 0.3 |
| Oct. 14 | 7.1 | 6.9-7.3 | 7.1 | 7.0-7.3 | 0.0 |
| Nov. 12 | 3.1 | 3.0-3.3 | 2.6 | 2.6-2.7 | -0.5 |




HOUR

FIG. 10 . AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK B (—) AND DEFOLIATED BLOCK A (---) ON MAY 19, 1977.



SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
oC
15
10
5
0
6
12
18
24
HOUR

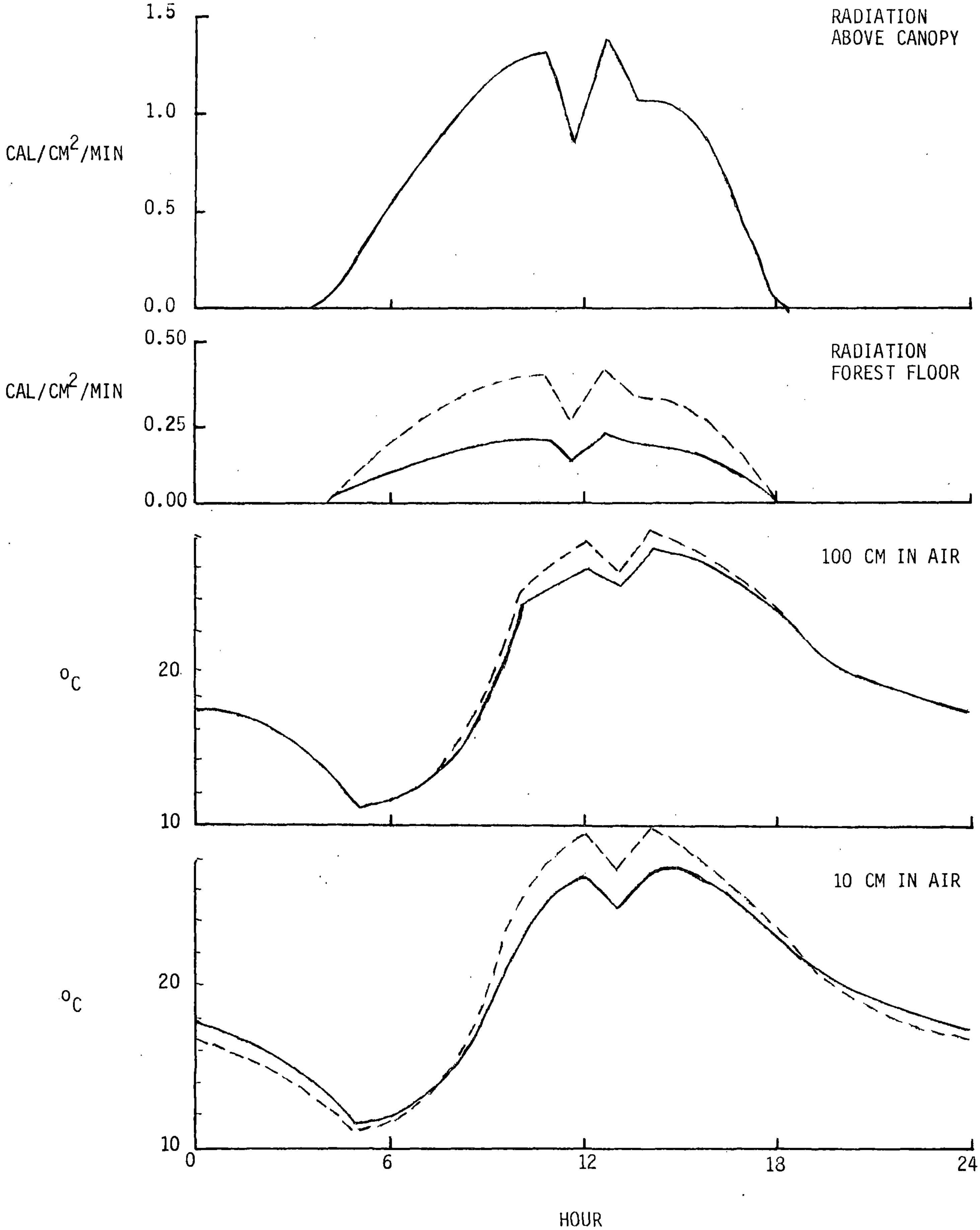
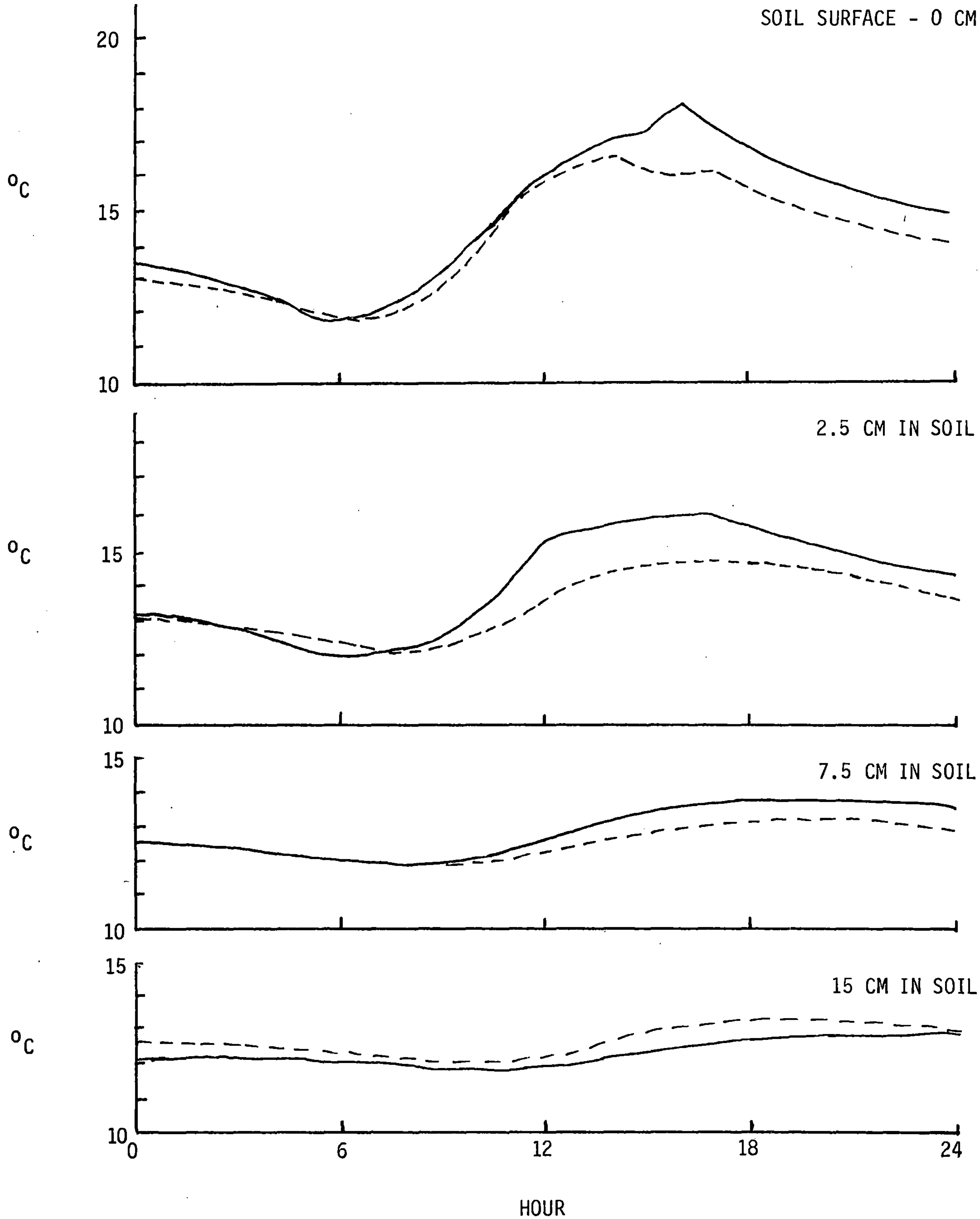



FIG. 11. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK B (——) AND DEFOLIATED BLOCK A (---) ON JUNE 24, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
20
15
10
0
6
12
18
24
HOUR

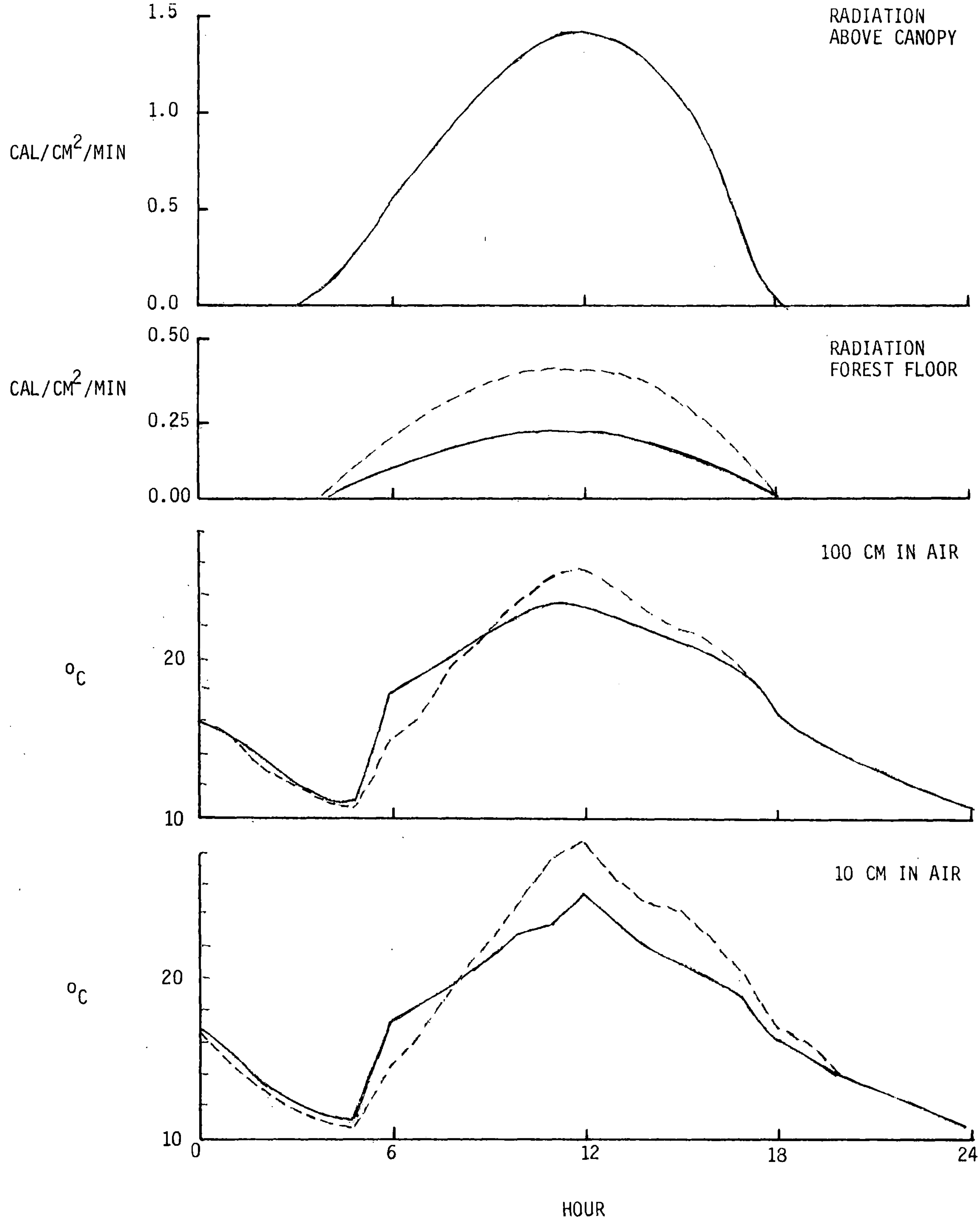
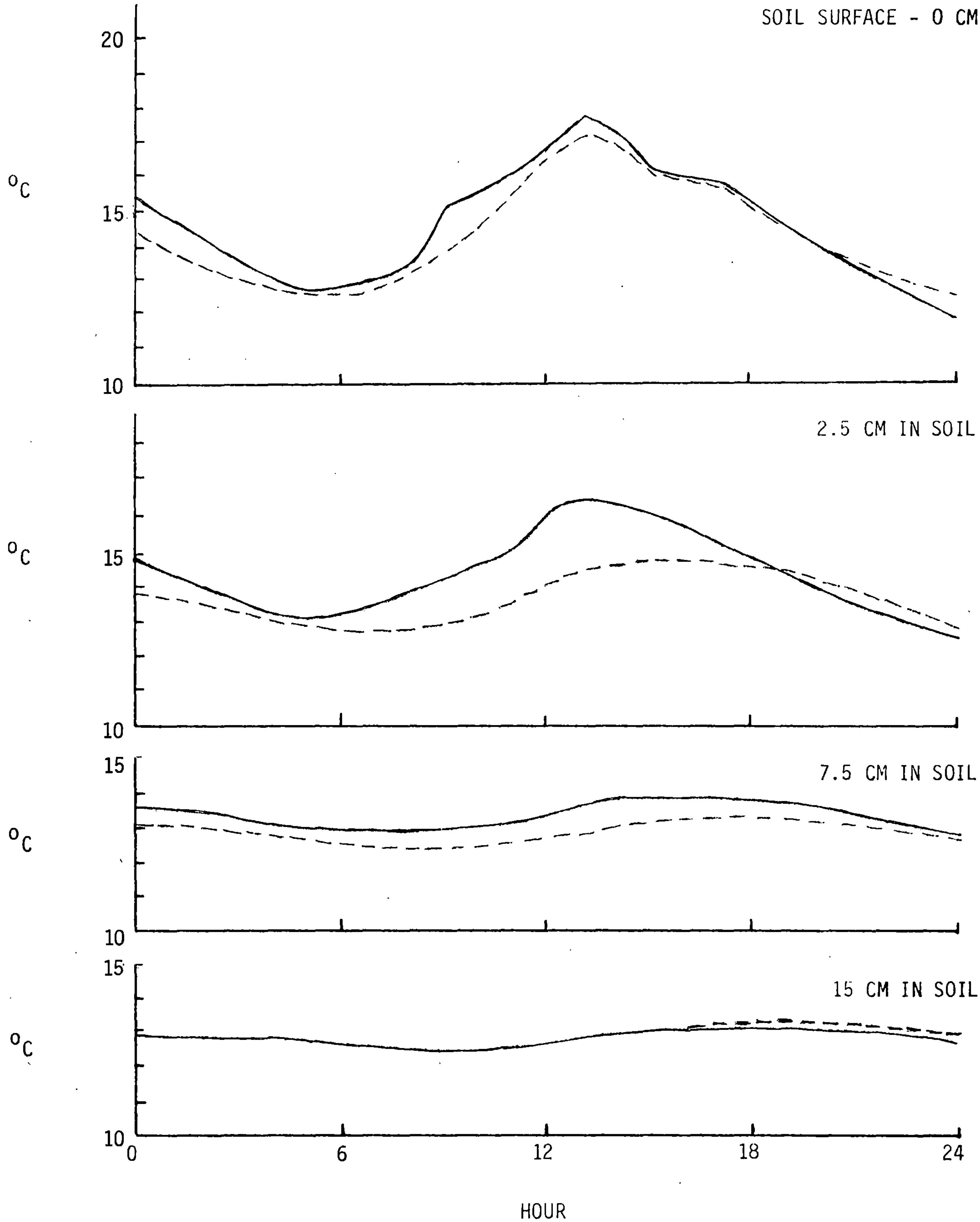



FIG. 12. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK B (—) AND DEFOLIATED BLOCK A (---) ON JULY 1, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
20
15
10
0
6
12
18
24
HOUR

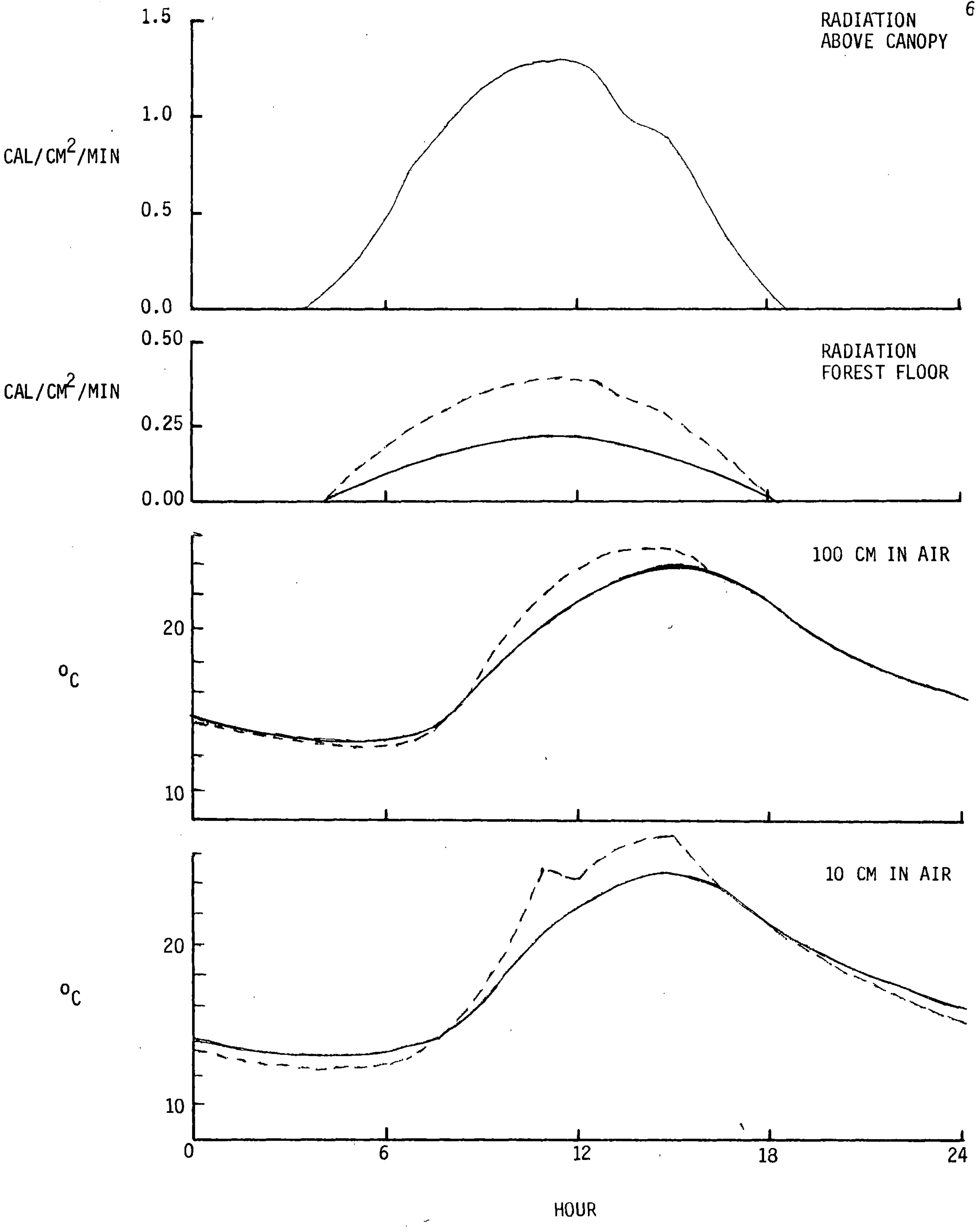
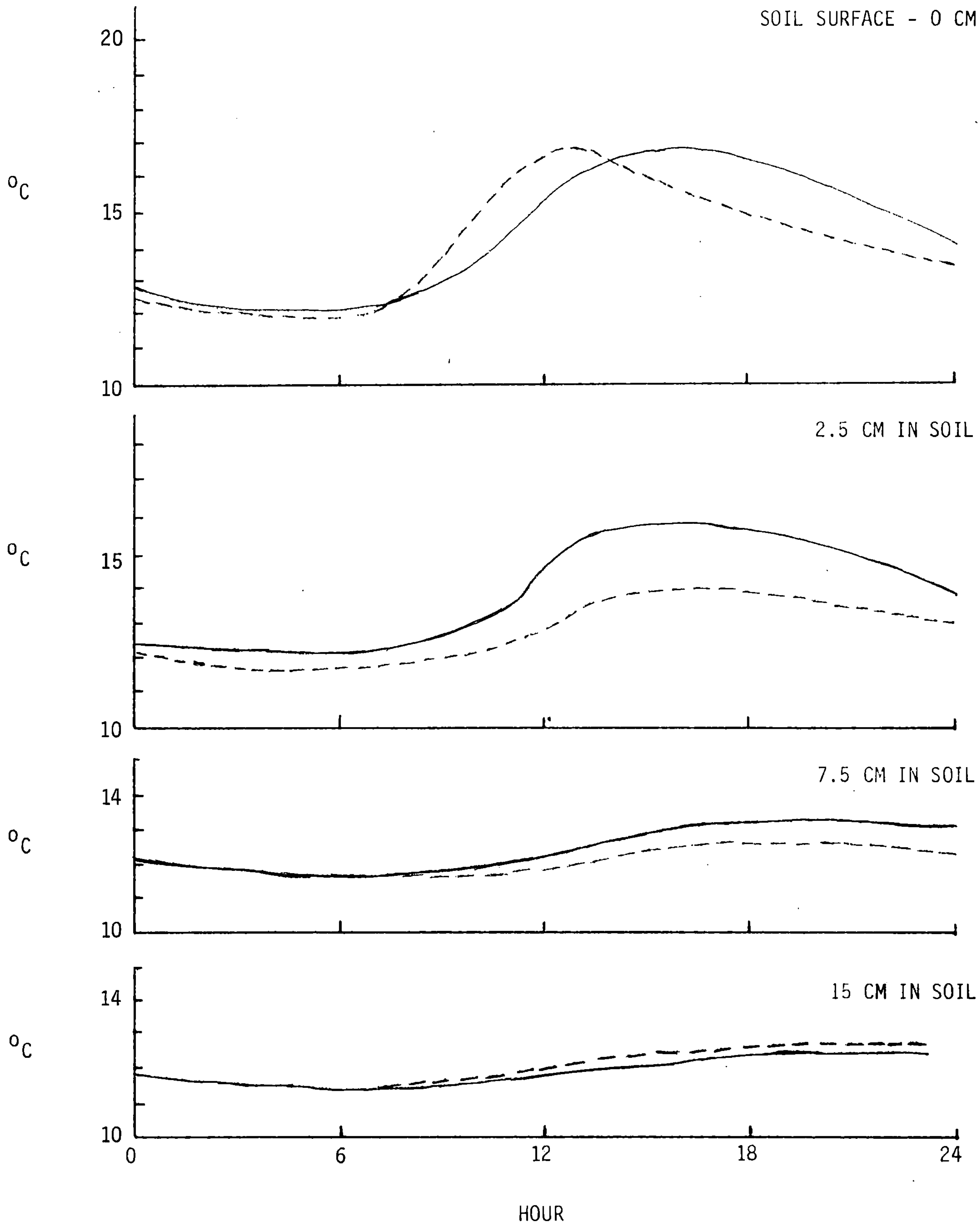



FIG.13 . AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK B (——) AND DEFOLIATED BLOCK A (---) ON JULY 14, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
20
15
10
14
0
6
12
18
24
HOUR

Without continuous temperature data for the entire year and the colder pre-defoliation soil temperatures in Block A noted earlier, it is difficult to appreciate the full value of replication one in 1977. However, some important observations are available. As observed in August 1976, air temperatures at both the 100-cm and 10-cm levels were warmer in Block A than in Block B in the four periods shown for 1977 (Tables 8 and 9). Air temperatures correspond very well with radiation levels for the four representative days, indicating the minor influence of advected heat from outside the experimental area. On June 24 (Figure 11), a cloud passed over the experimental site near mid-day and air temperatures dropped rapidly and climbed again later in the day. This cloud effect appeared to have a larger influence on lowering soil temperatures in the treatment area than the control, possibly due to differences in the stand's heat capacities.

For Blocks A and B the soil temperatures were warmer on May 19 in the treatment area than in the control (Tables 10-14). Since pre-treatment calibration showed that the control Block B soil temperatures were noticeably warmer than Block A, the increases in the May 19 temperatures are probably much larger, possibly 0.1 to 2.0$^{o}$ C warmer than shown. Due to this calibration procedure, it also appears that soil temperatures have been increased slightly by defoliation on June 24 and July 1 and 13. However, the defoliation treatment only increased the average penetration of diffused radiation as estimated by canopy photographs by 7.9 percent, which may have been too low to see large treatment differences in soil temperatures.

Continuous data on radiation, air temperatures, and soil temperatures were recorded on Blocks C and E during 1977. Clear day peak solar radiation above the canopy ranged from 0.46 cal/cm$^2$/min on February 19 to 1.29 cal/cm$^2$/min on July 1, and returned to 0.80 cal/cm$^2$/min on November 12. Differences in diffuse radiation penetrating the two canopies (Figures 14-23) are based on the hemispherical photographs for the individual temperature measurement locations. These values were 41.0 percent for Block C and 21.3 percent for Block E.

Temperature data represented by the 14 days over a 10-month period in 1977 show rather important trends which could not be achieved with the limited sampling periods used in 1976. Mean air temperatures were shown to be warmer in the defoliated stand than in the control stand. This positive temperature difference only appears to continue from early May to early September. During the winter period colder air temperatures were observed in the defoliated stand. These differences clearly illustrate the influence of conifer foliage on stand radiation interception and heat storage. Although the differences in temperature between stands were not large, these differences may have been minimized by the size of our treatment area.

During February 1977, a residual snowpack was observed in the defoliated blocks while the snow cover was absent in the control blocks. Although snow accumulation may have been different under the two stand conditions, warmer air temperatures as we observed in the control stand should have contributed to the differential snowmelt rates.

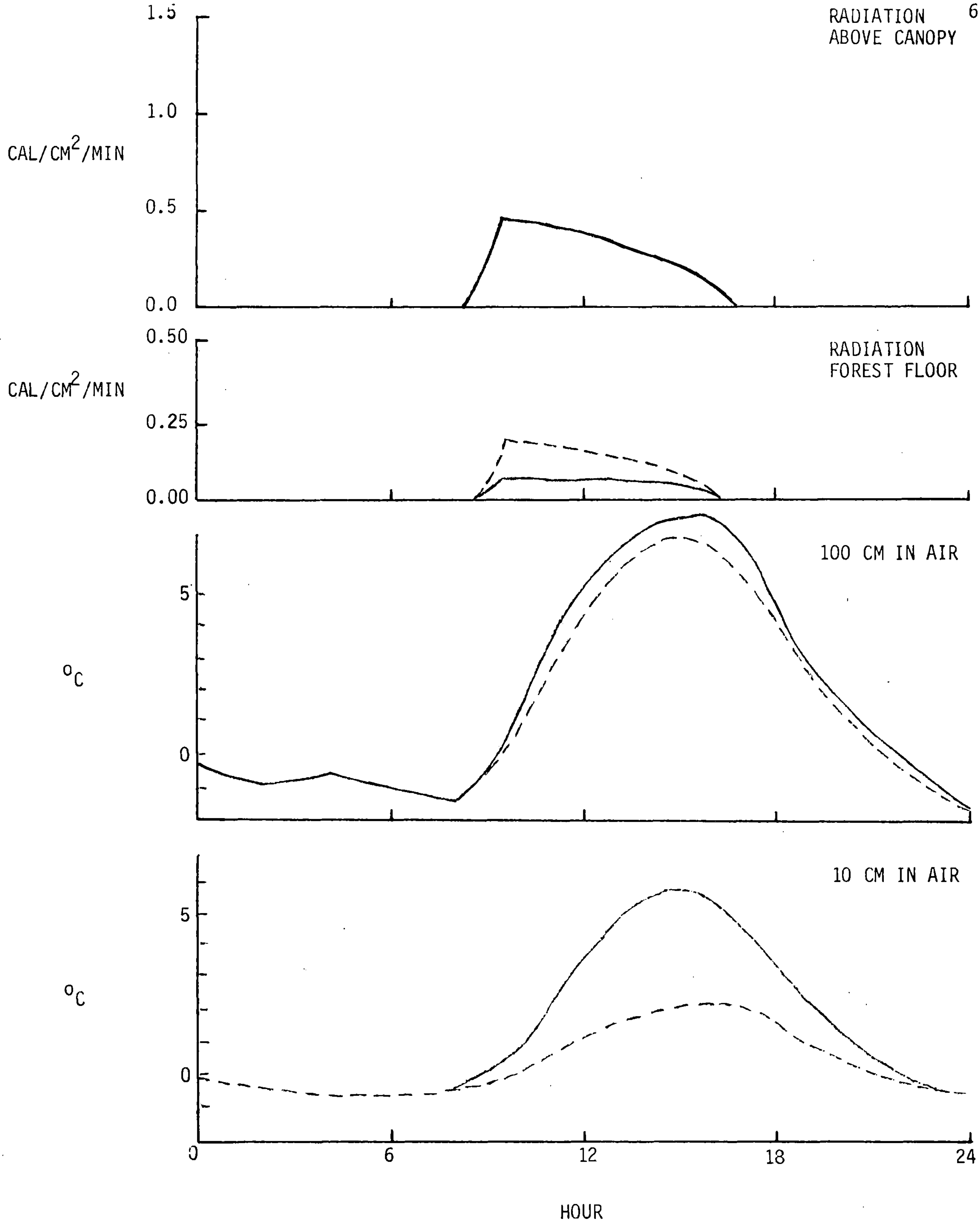
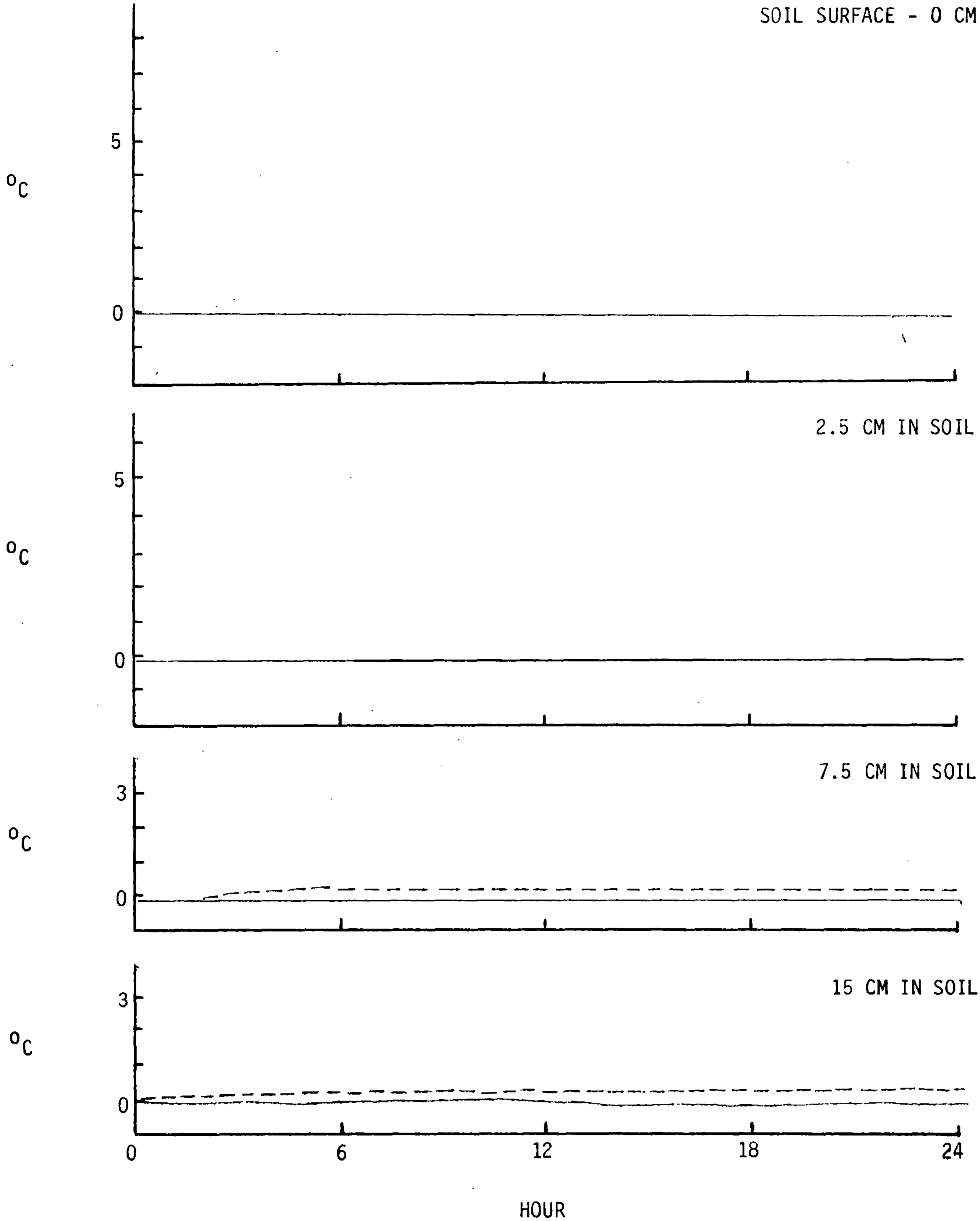



FIG. 14. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON FEBRUARY 18, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
5
0
3
0
6
12
18
24
HOUR

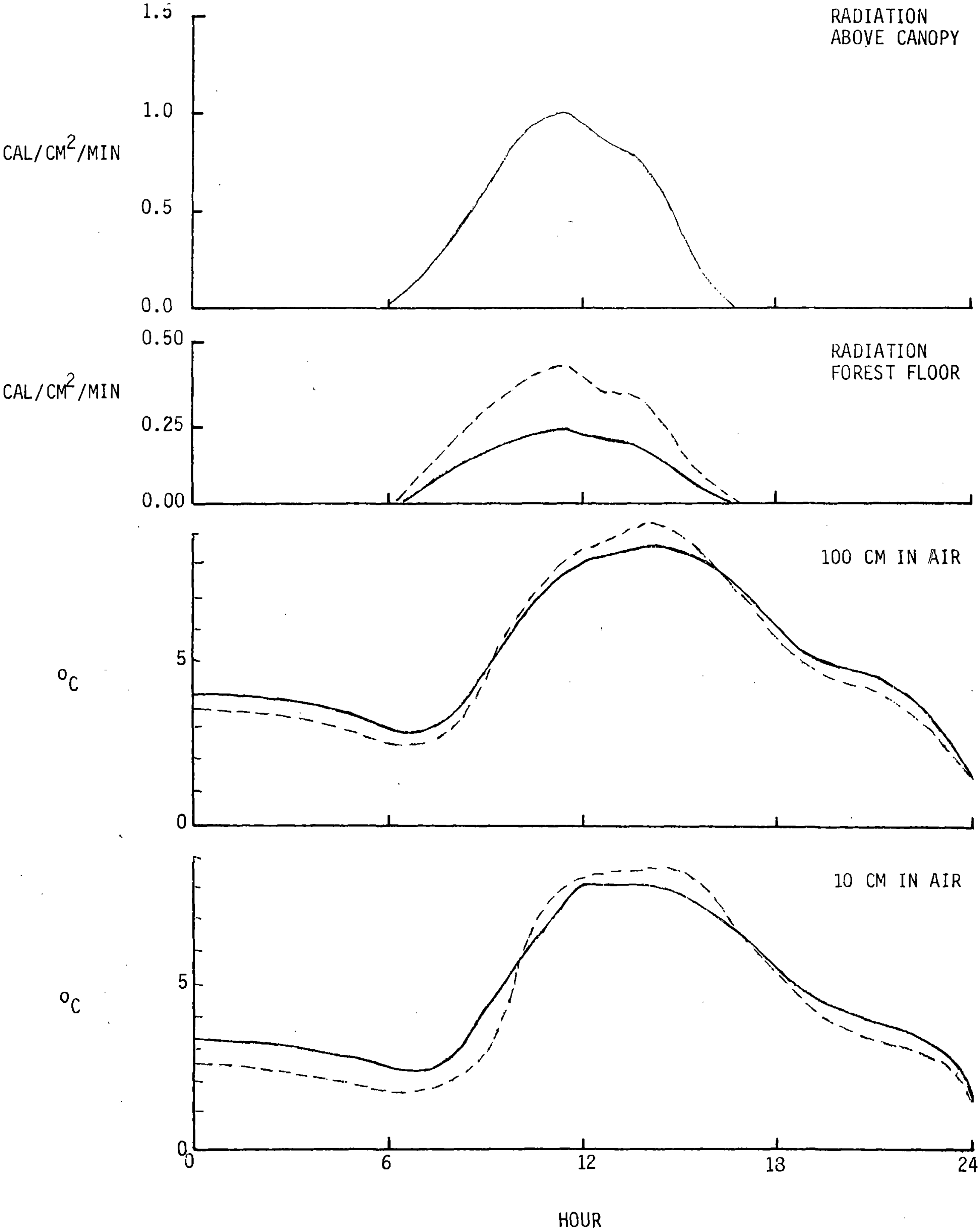
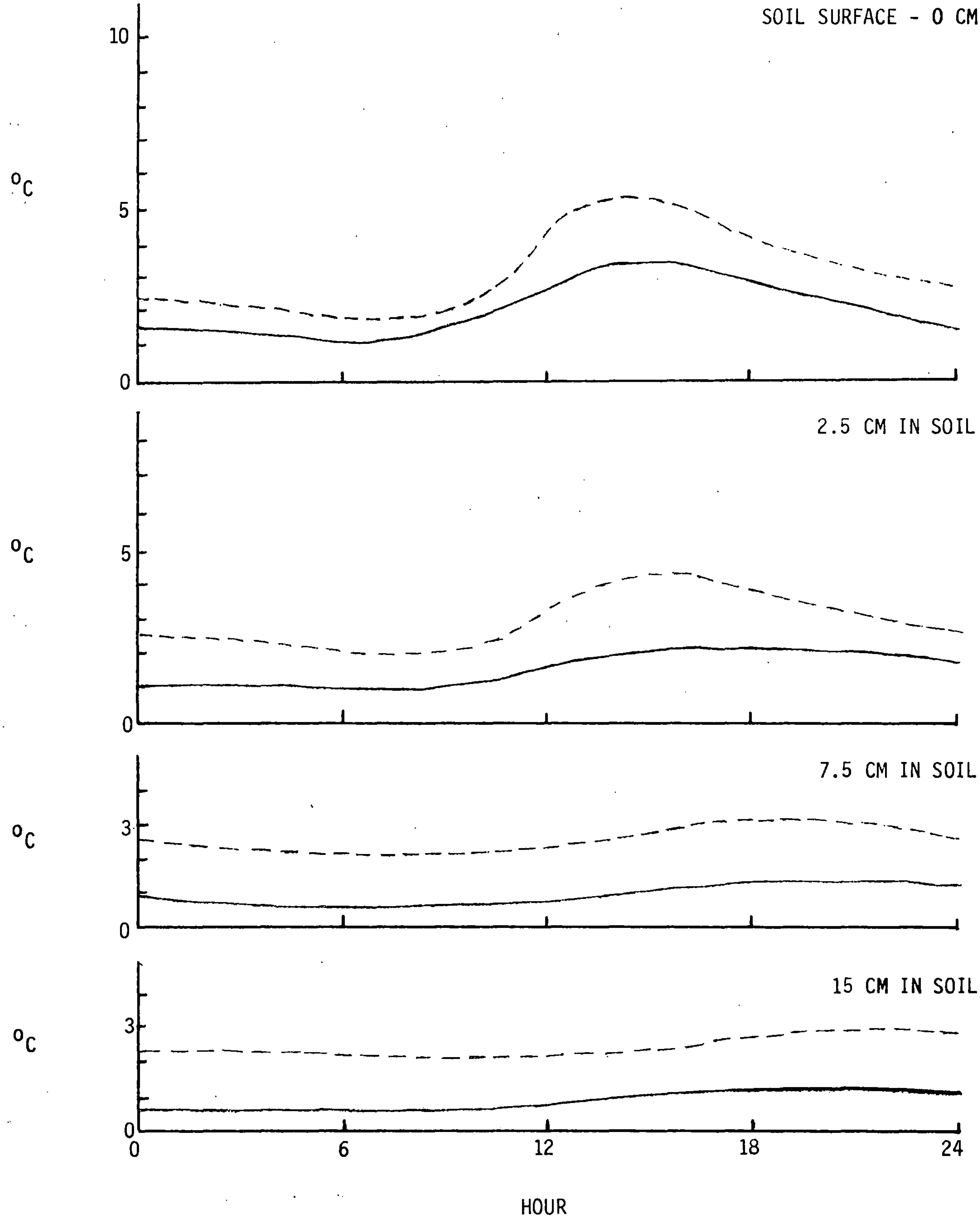



FIG. 15. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON APRIL 1, 1977.



SOIL SURFACE - 0 CM
10
5
0
°C
2.5 CM IN SOIL
5
0
°C
7.5 CM IN SOIL
3
0
°C
15 CM IN SOIL
3
0
°C
0
6
12
18
24
HOUR

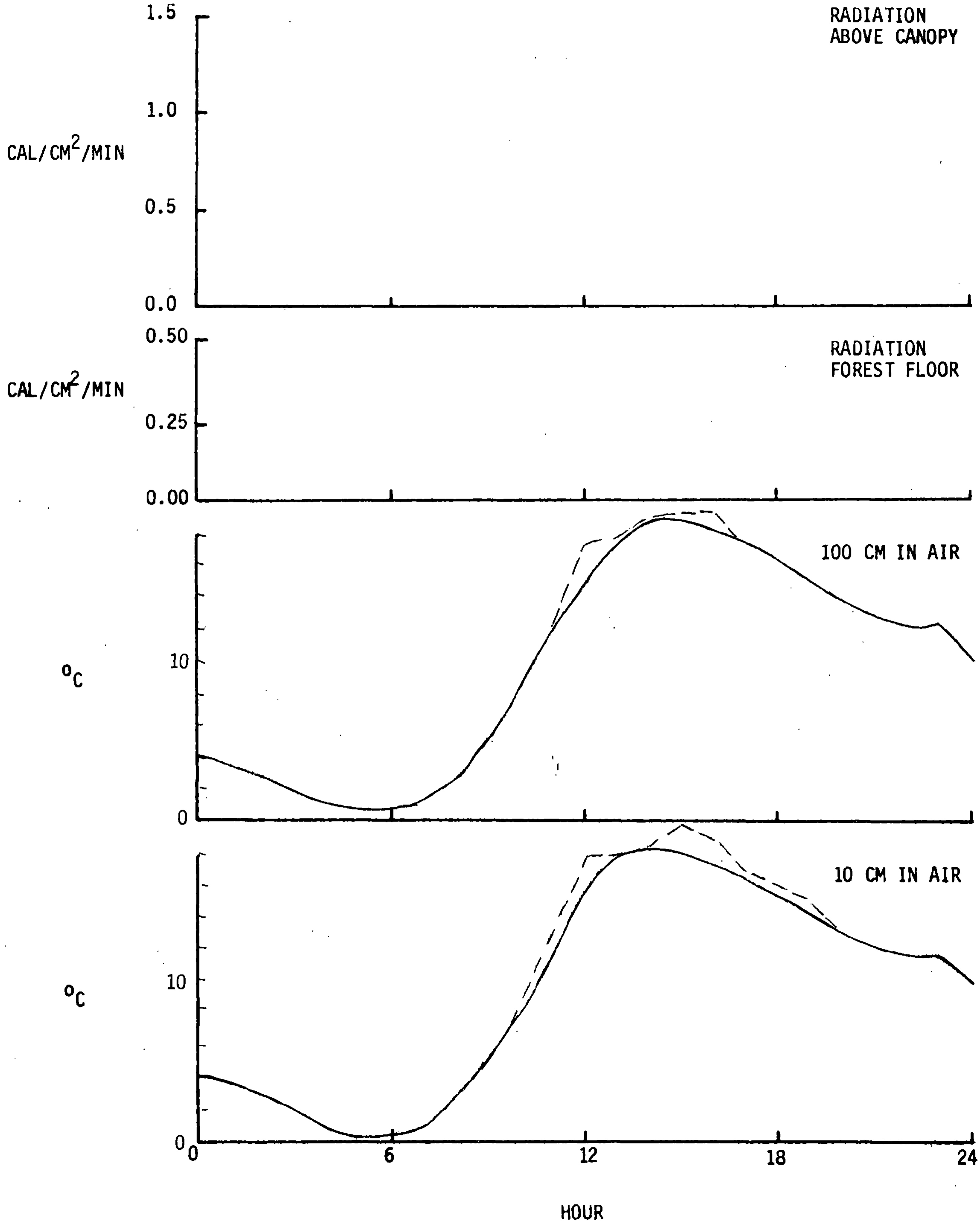
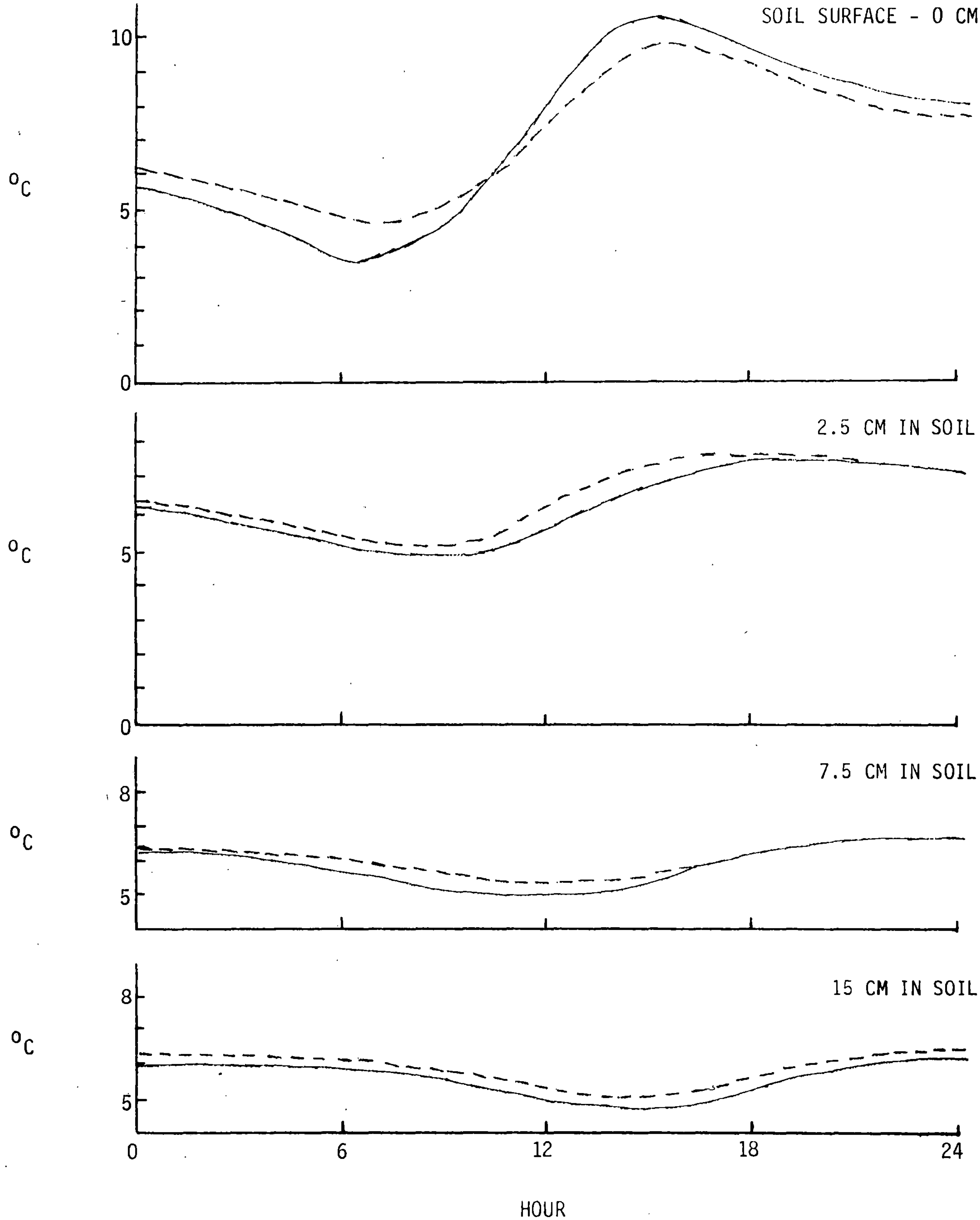



FIG. 16. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (—) AND DEFOLIATED BLOCK C (---) ON APRIL 28, 1977.



SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
°C
°C
°C
10
5
0
5
0
8
5
8
5
0
6
12
18
24
HOUR

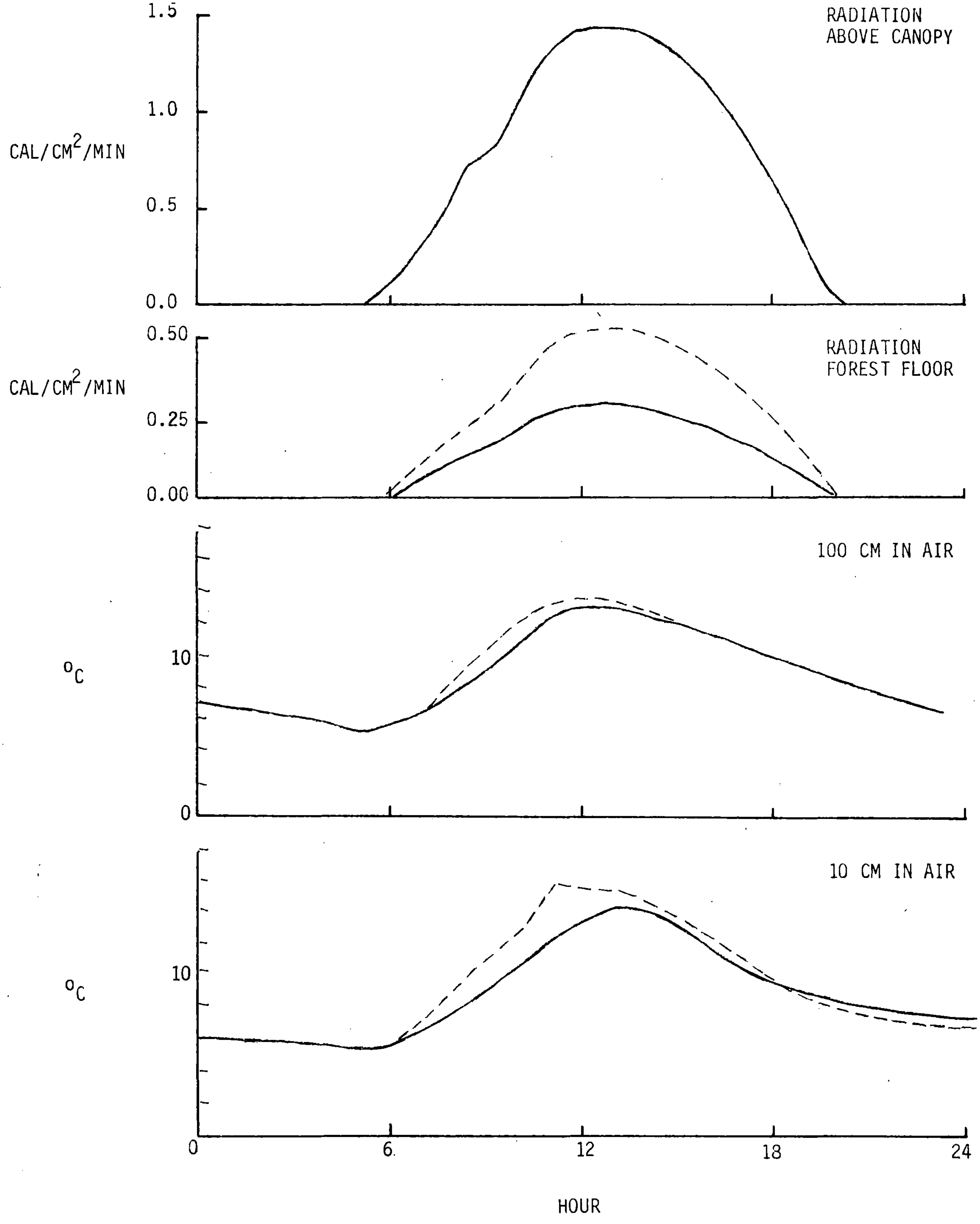
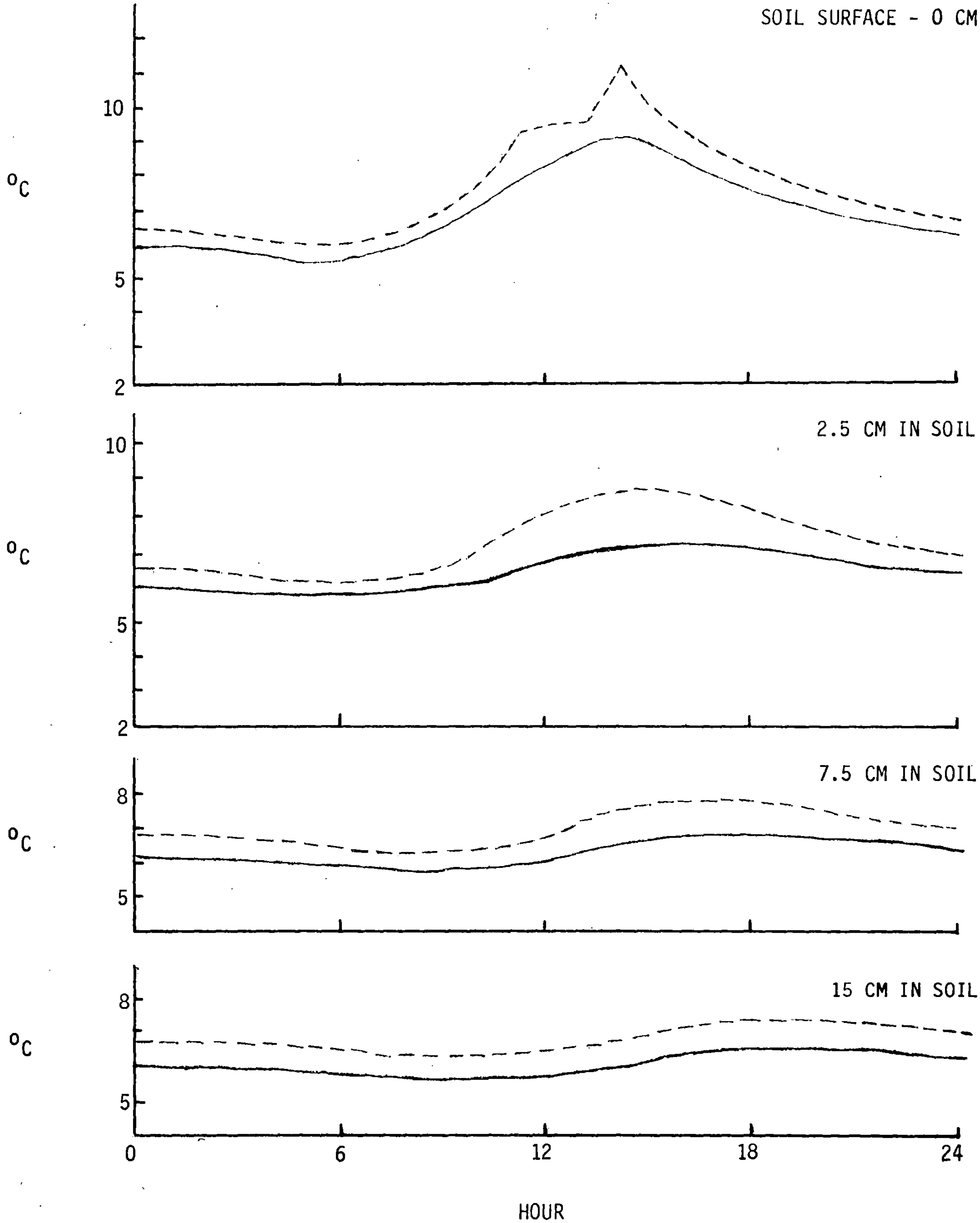



FIG. 17 . AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON MAY 19, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
10
5
2
8
0
6
12
18
24
HOUR

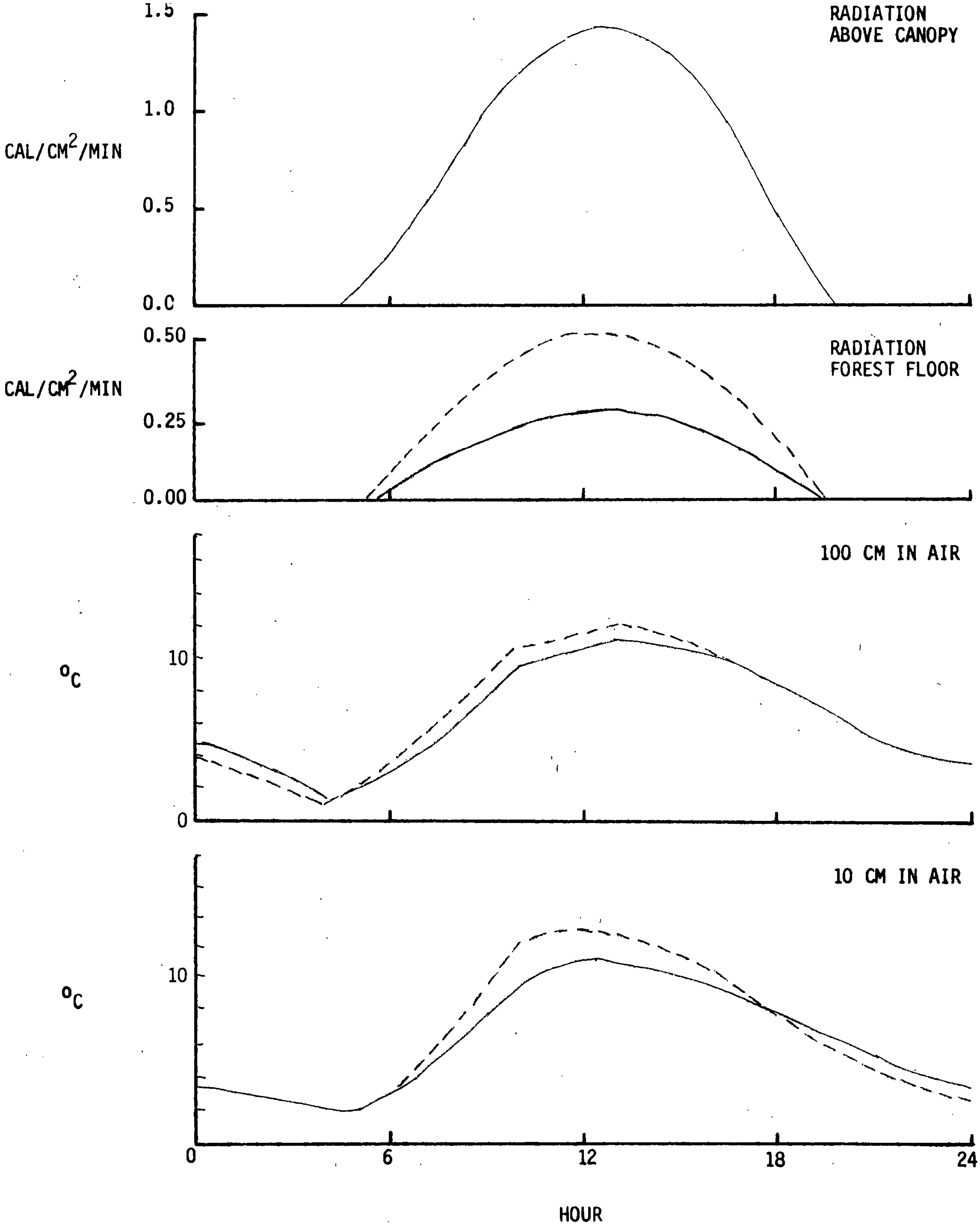
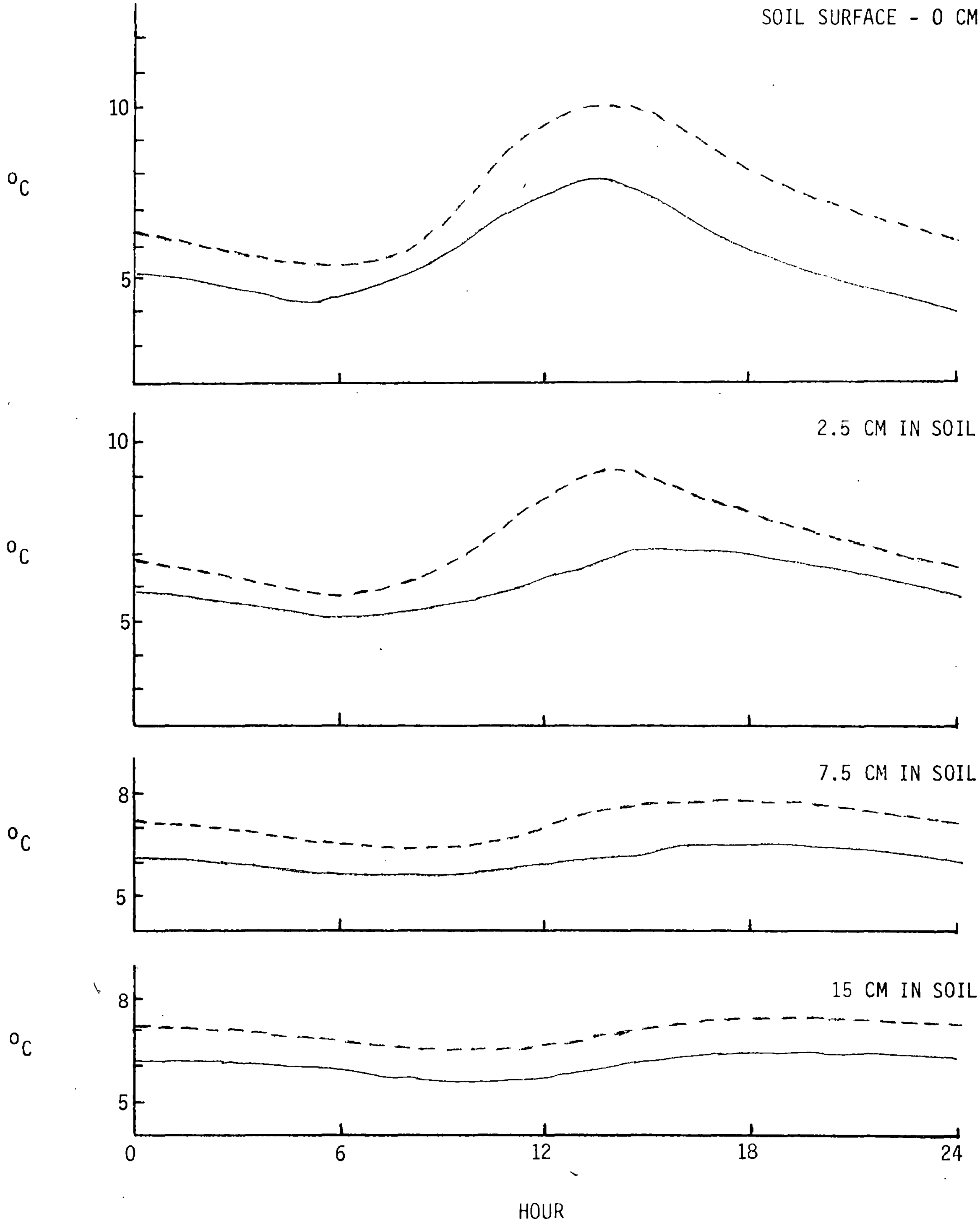



FIG. 18. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON APRIL 28, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
10
5
8
0
6
12
18
24
HOUR

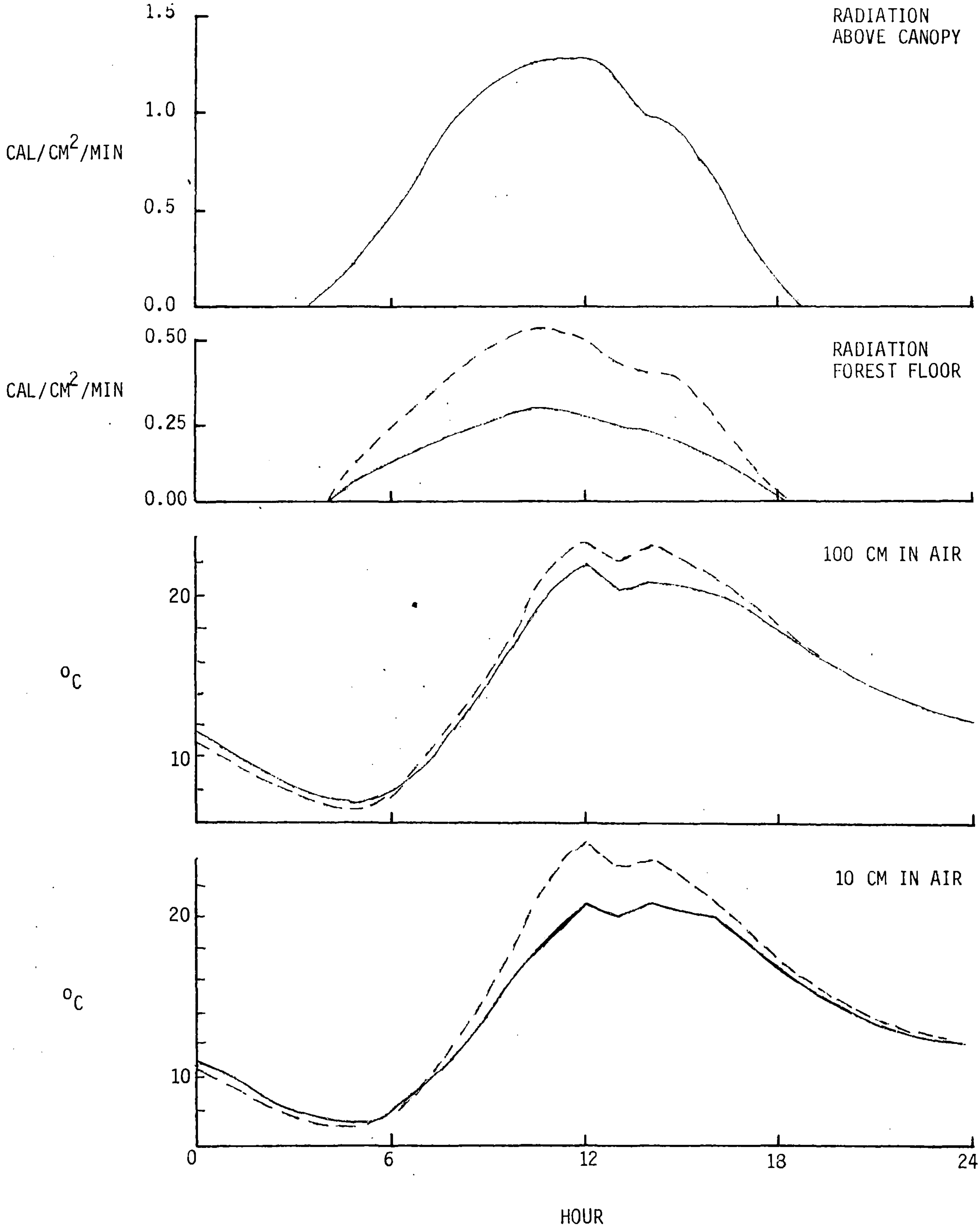
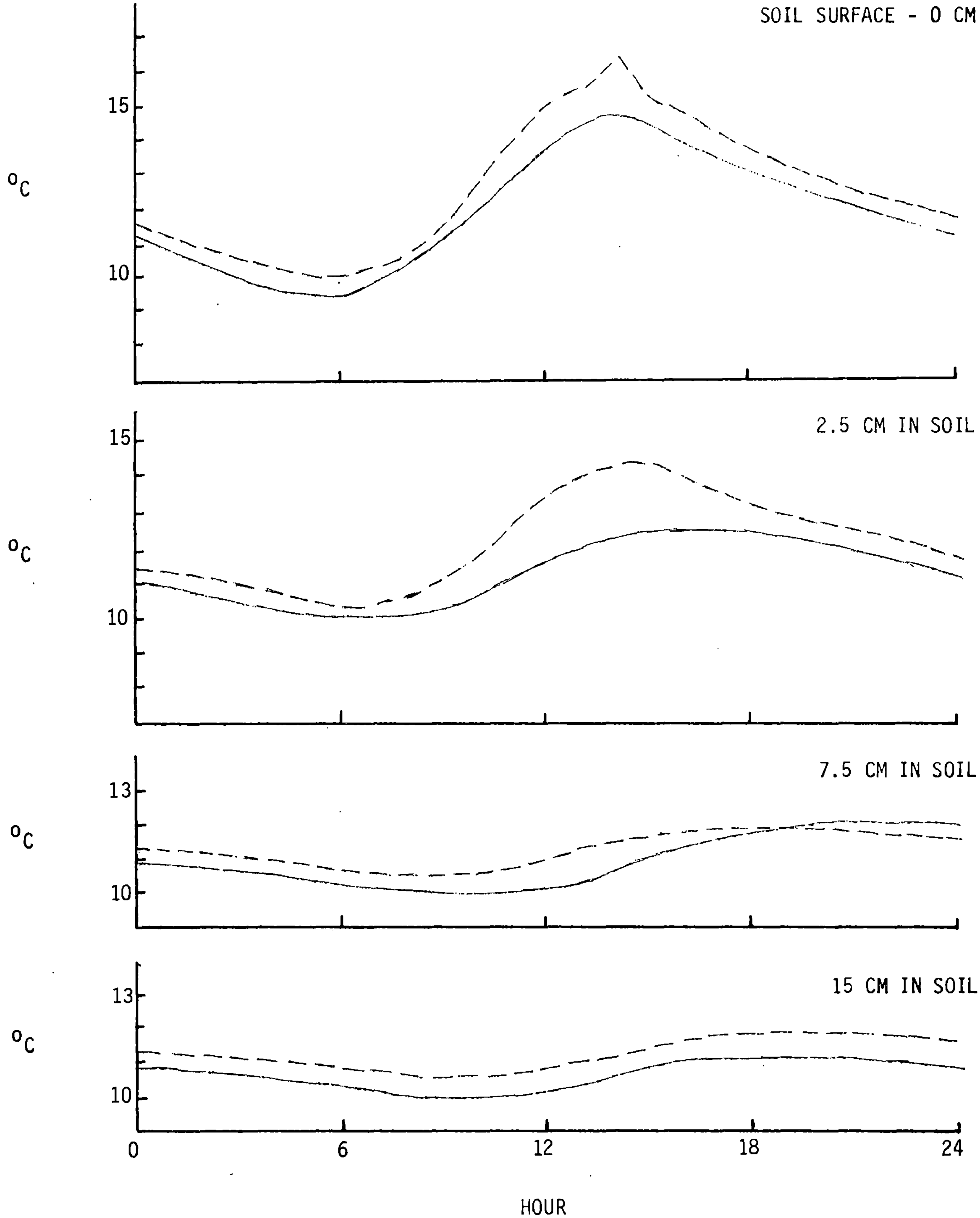



FIG. 19 . AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON JUNE 14, 1977.


SOIL SURFACE - 0 CM
15
10
°C
2.5 CM IN SOIL
15
10
°C
7.5 CM IN SOIL
13
10
°C
15 CM IN SOIL
13
10
°C
0
6
12
18
24
HOUR

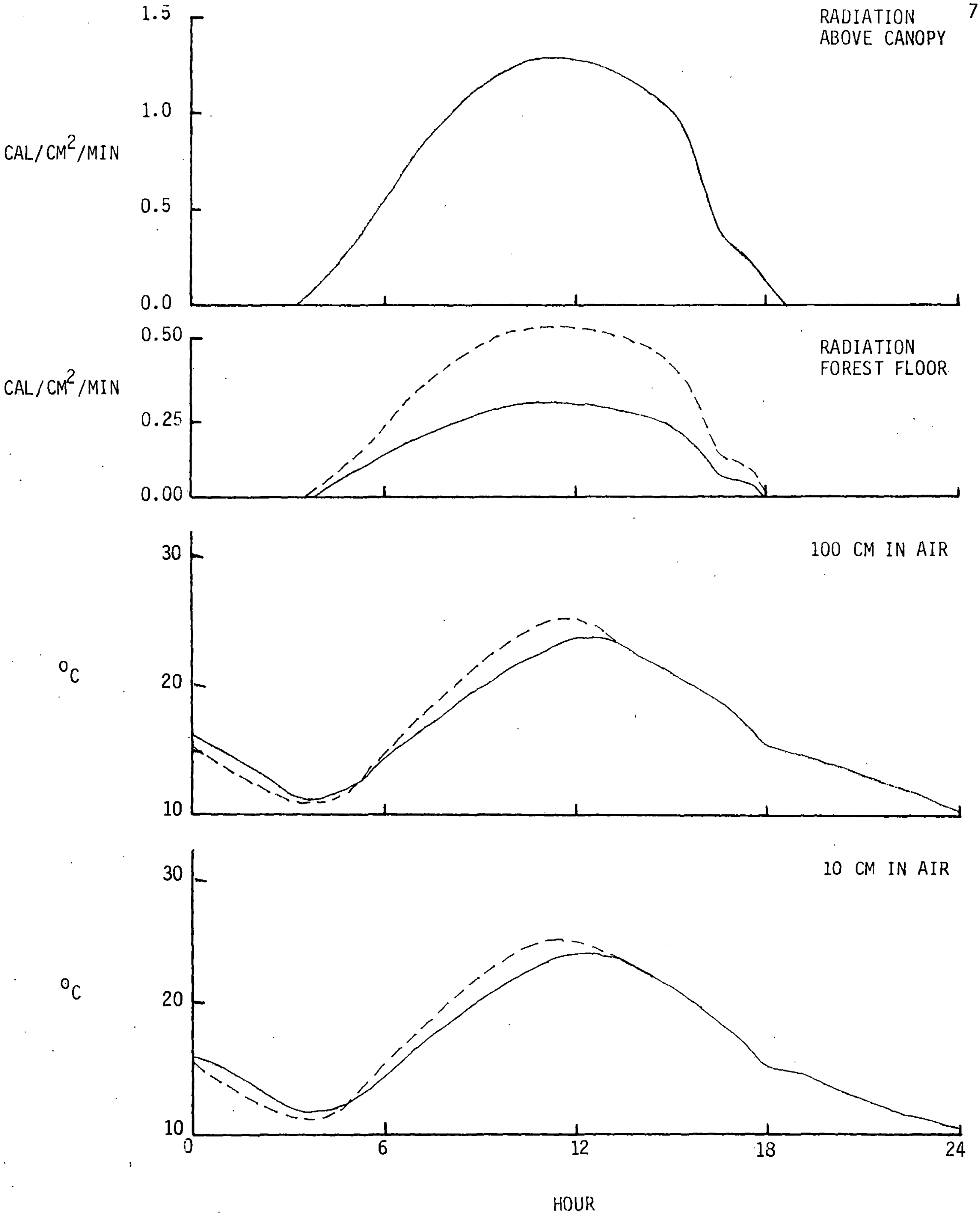
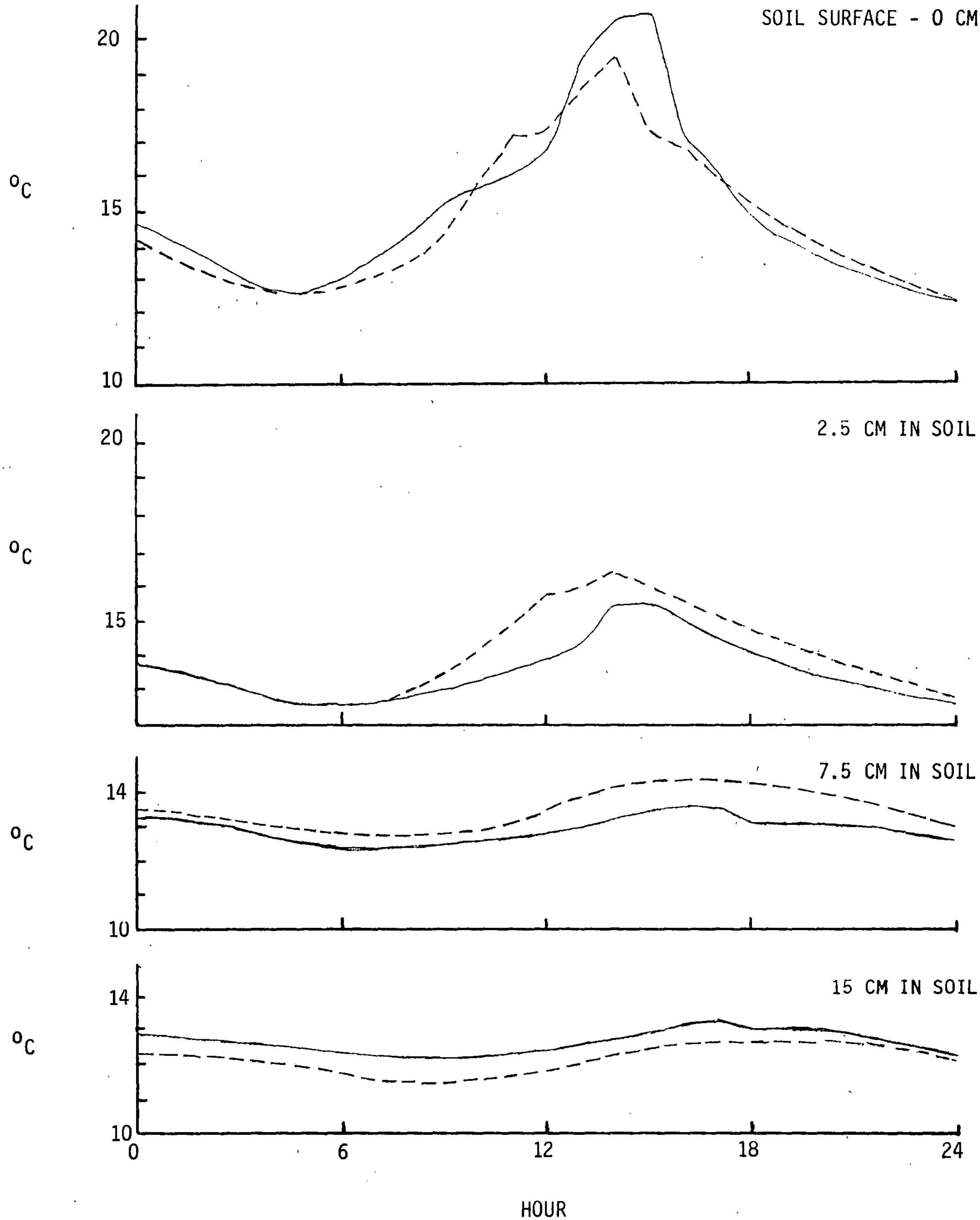



FIG. 20. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON JULY 1, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
20
15
10
14
0
6
12
18
24
HOUR

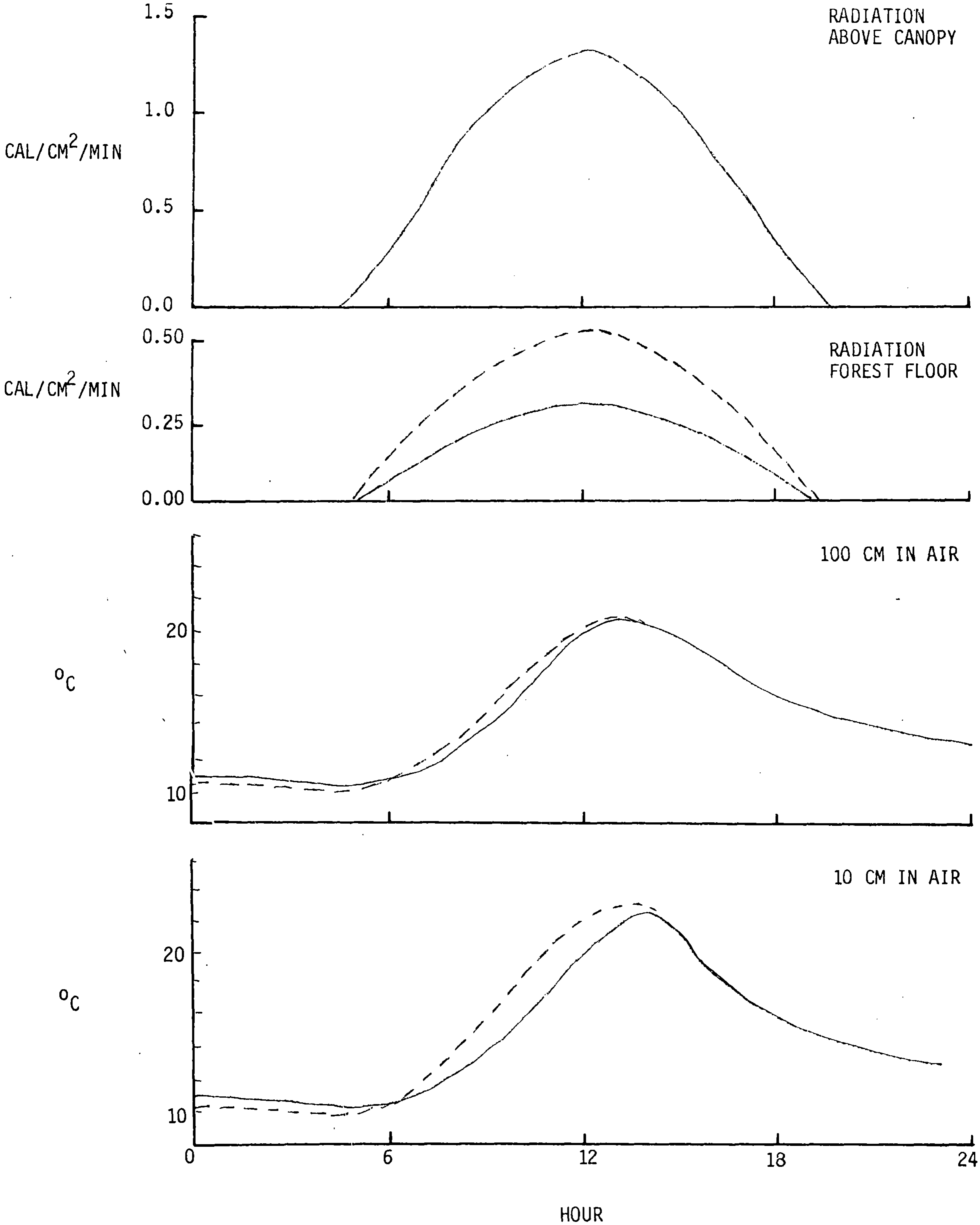
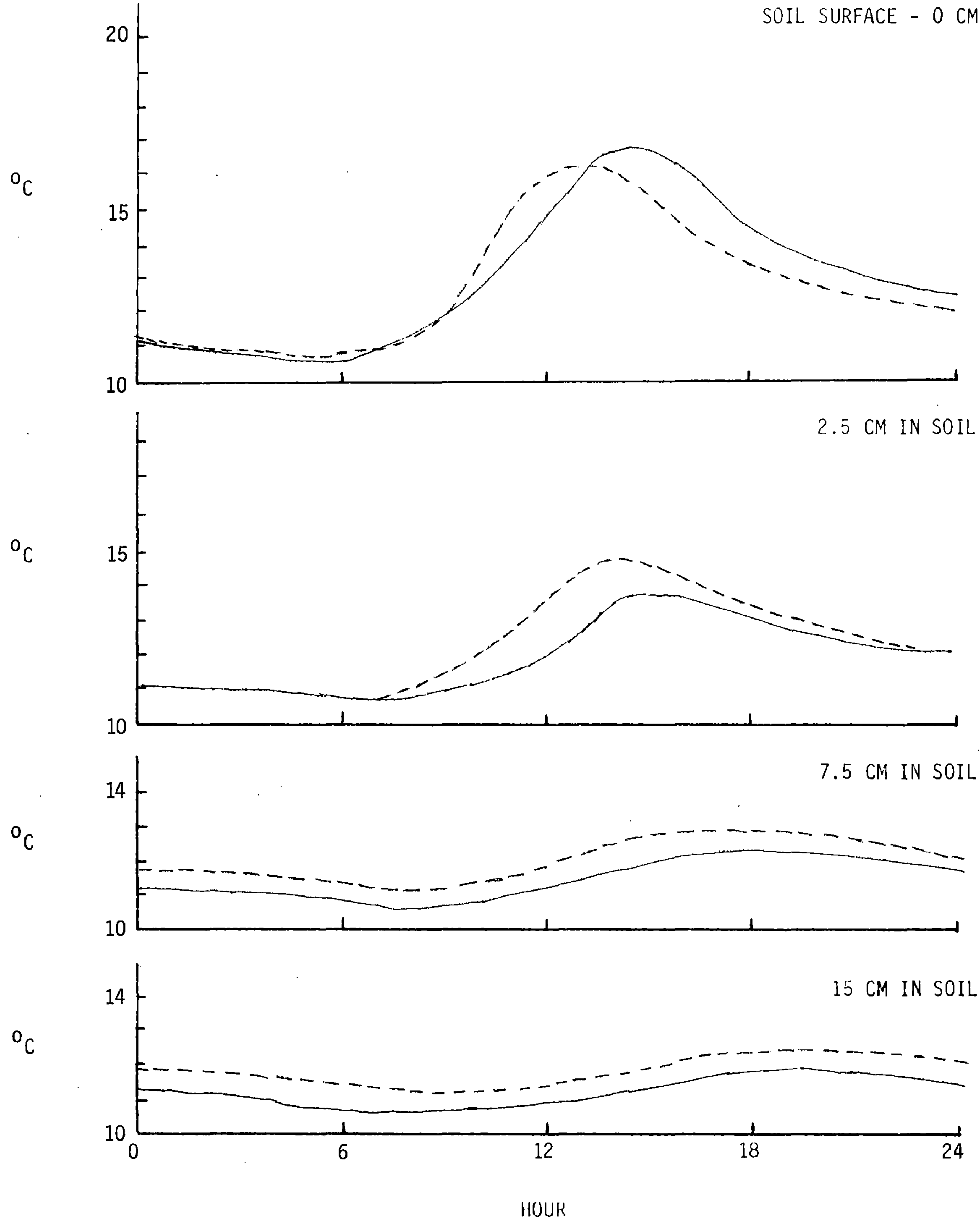



FIG. 21 . AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON JULY 13, 1977.


SOIL SURFACE - 0 CM
°C
20
15
10
2.5 CM IN SOIL
°C
15
10
7.5 CM IN SOIL
°C
14
10
15 CM IN SOIL
°C
14
10
0
6
12
18
24
HOUR

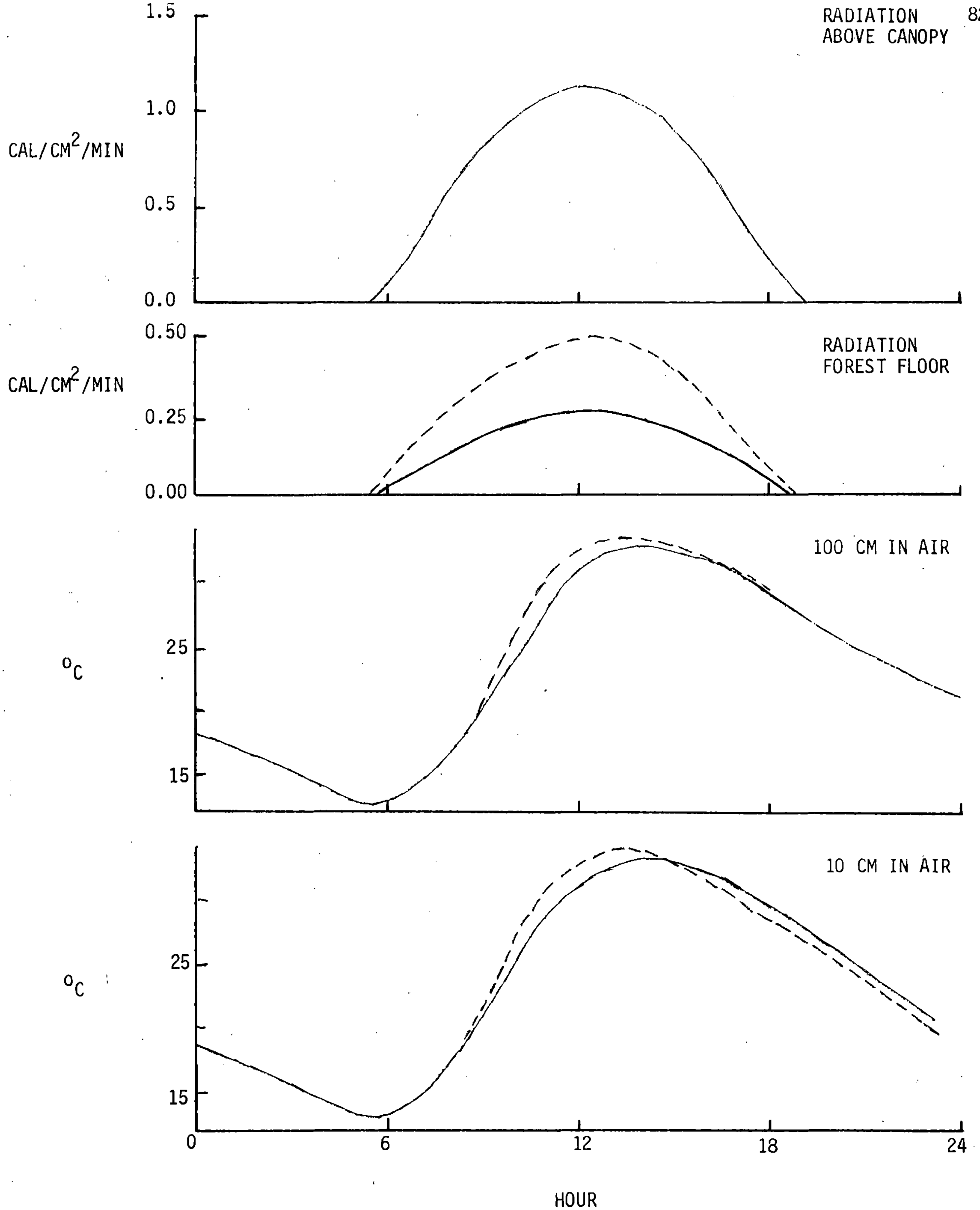
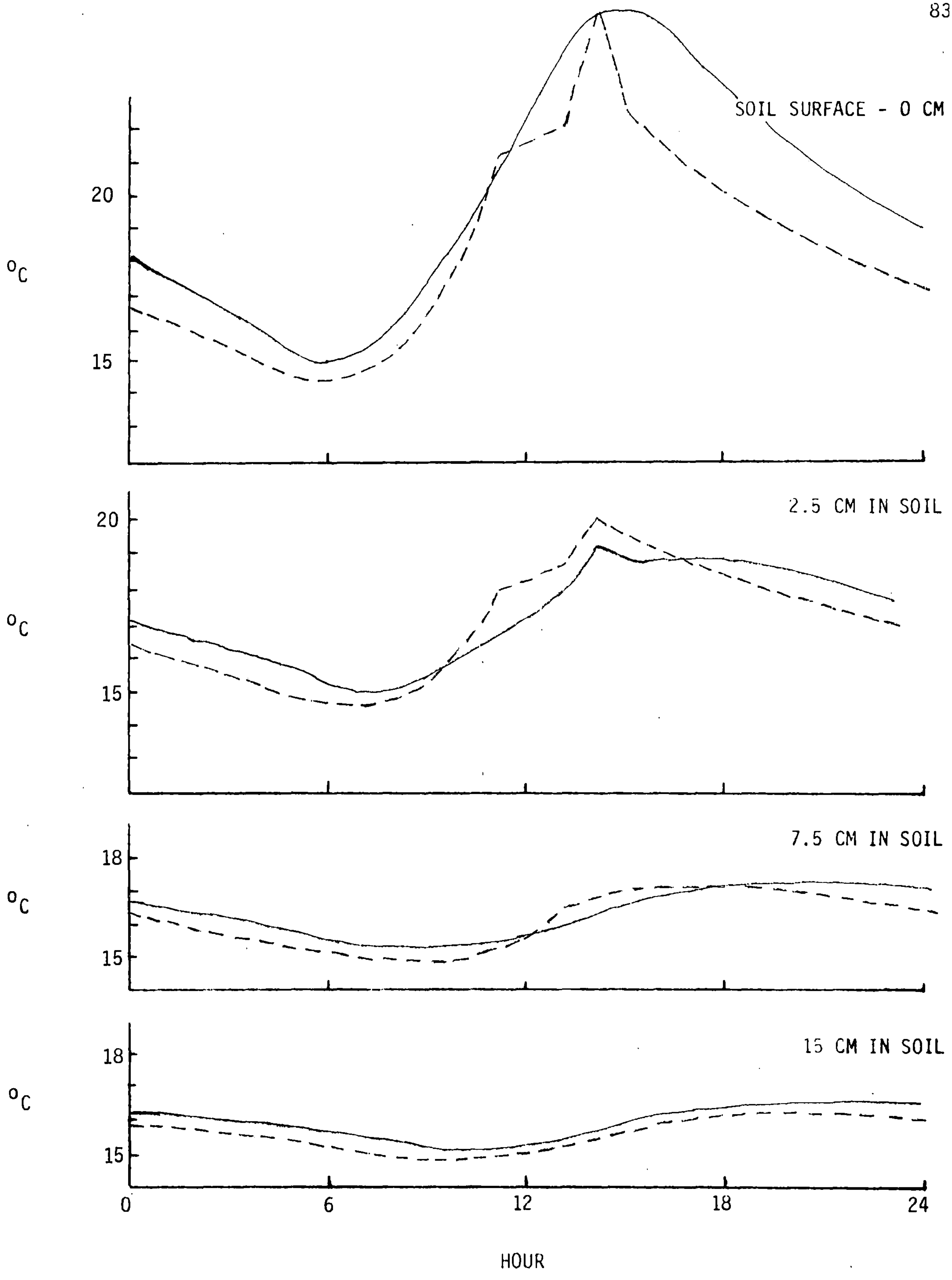



FIG. 22a. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON AUGUST 12, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
20
15
18
0
6
12
18
24
HOUR

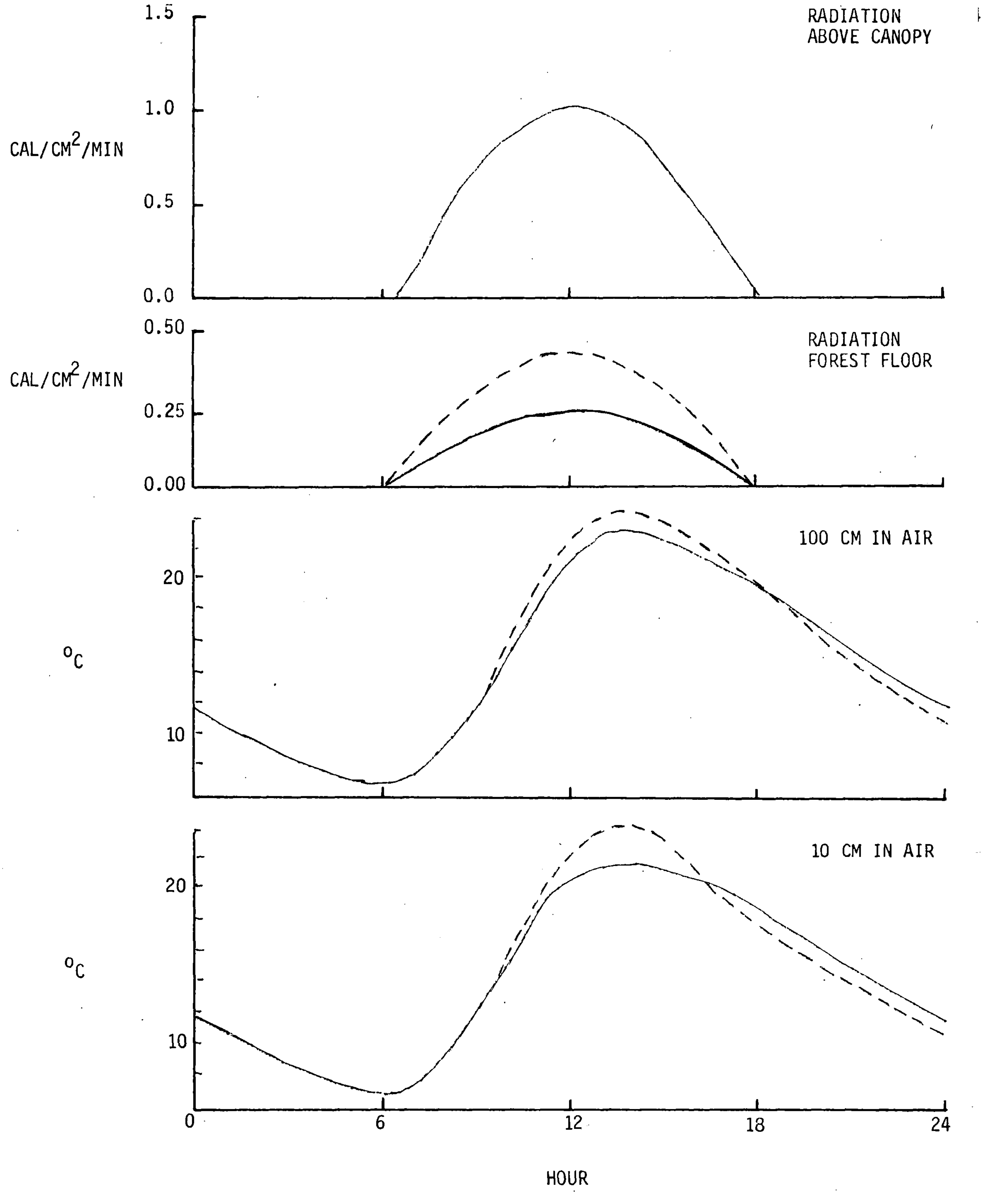
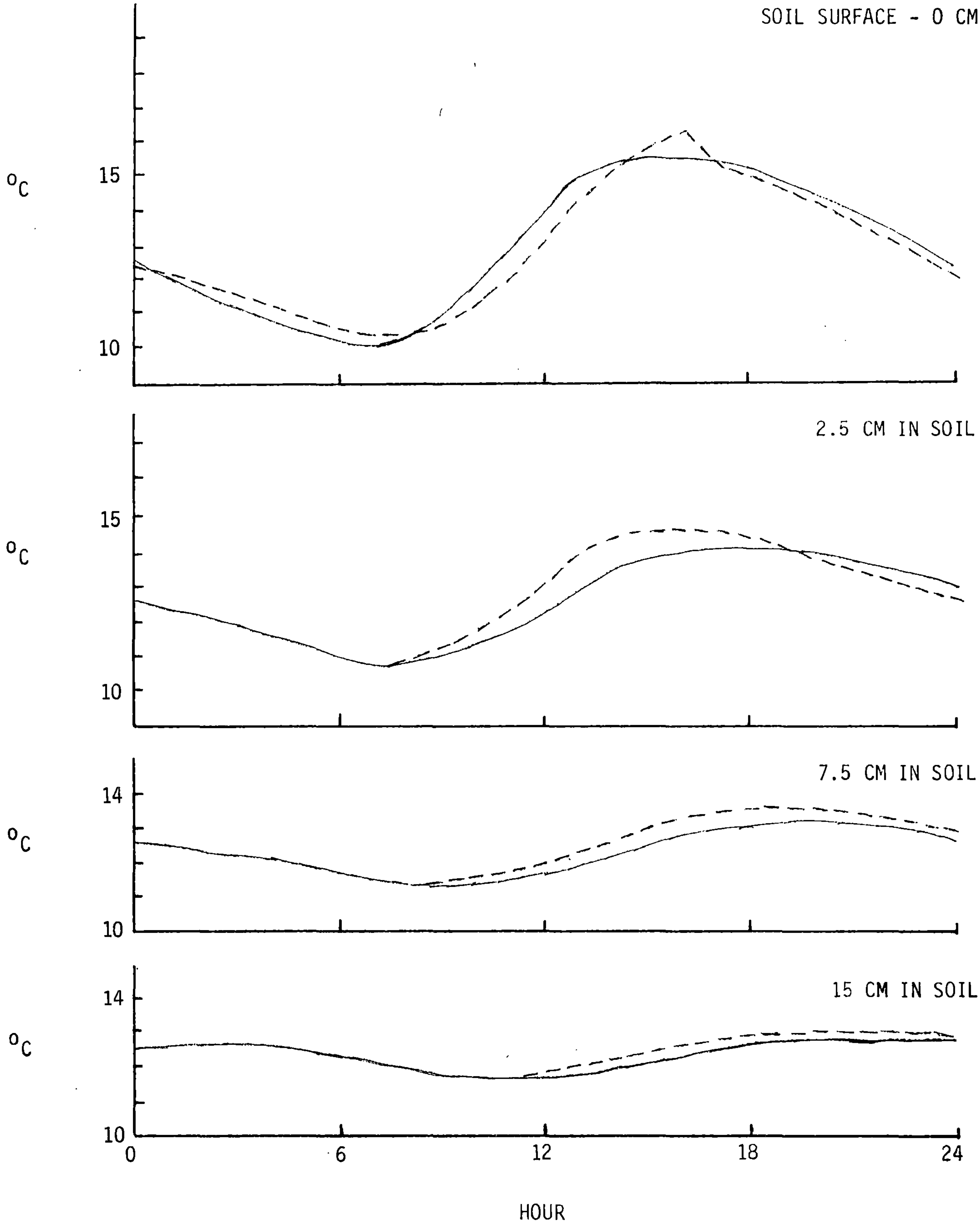



FIG. 22b AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON SEPTEMBER 12, 1977.


SOIL SURFACE - 0 CM
°C
15
10
2.5 CM IN SOIL
°C
15
10
7.5 CM IN SOIL
°C
14
10
15 CM IN SOIL
°C
14
10
0
6
12
18
24
HOUR

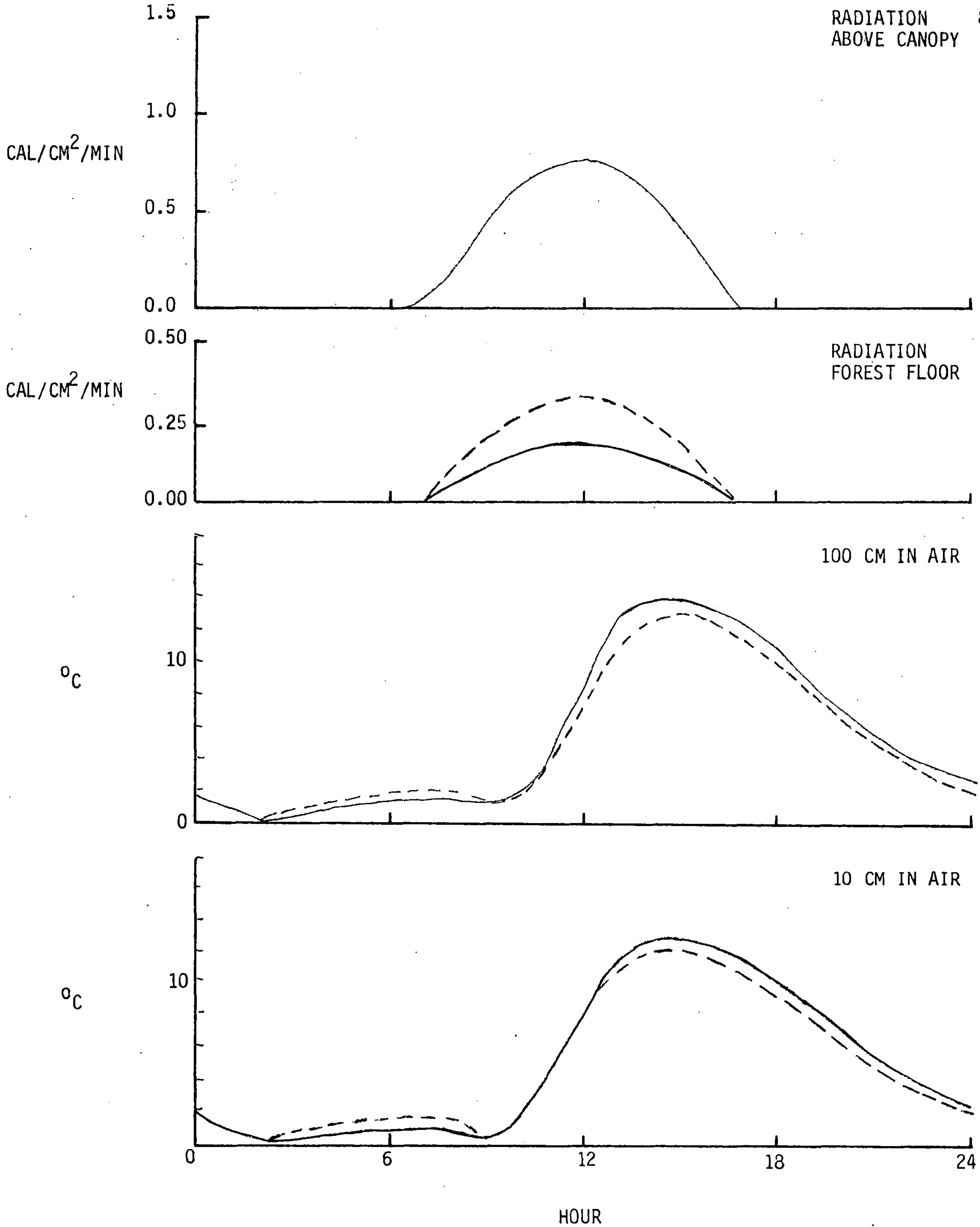
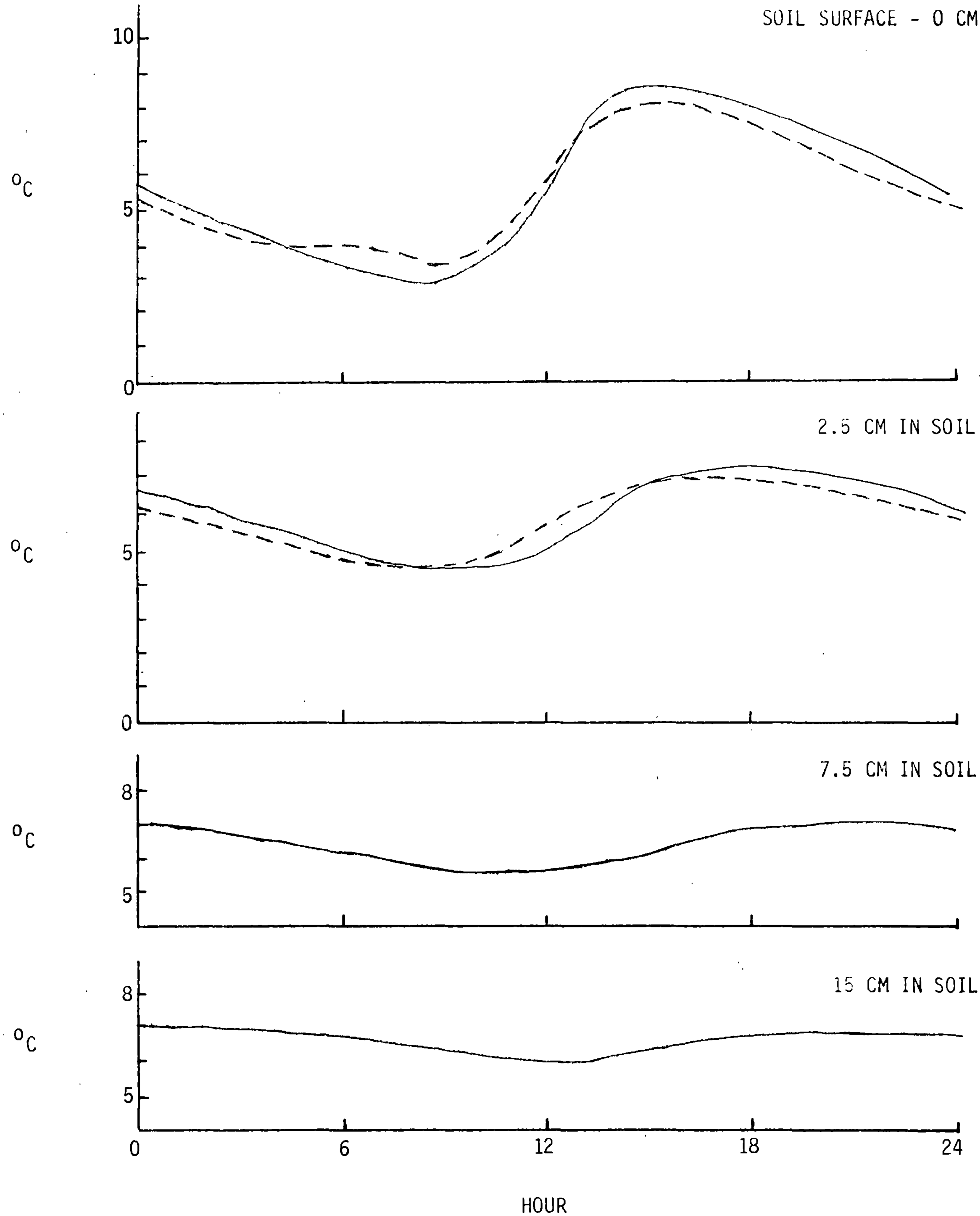



FIG. 22C. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (—) AND DEFOLIATED BLOCK C (---) ON OCTOBER 14, 1977.


SOIL SURFACE - 0 CM
10
5
0
oC
2.5 CM IN SOIL
5
0
oC
7.5 CM IN SOIL
8
5
oC
15 CM IN SOIL
8
5
oC
0
6
12
18
24
HOUR

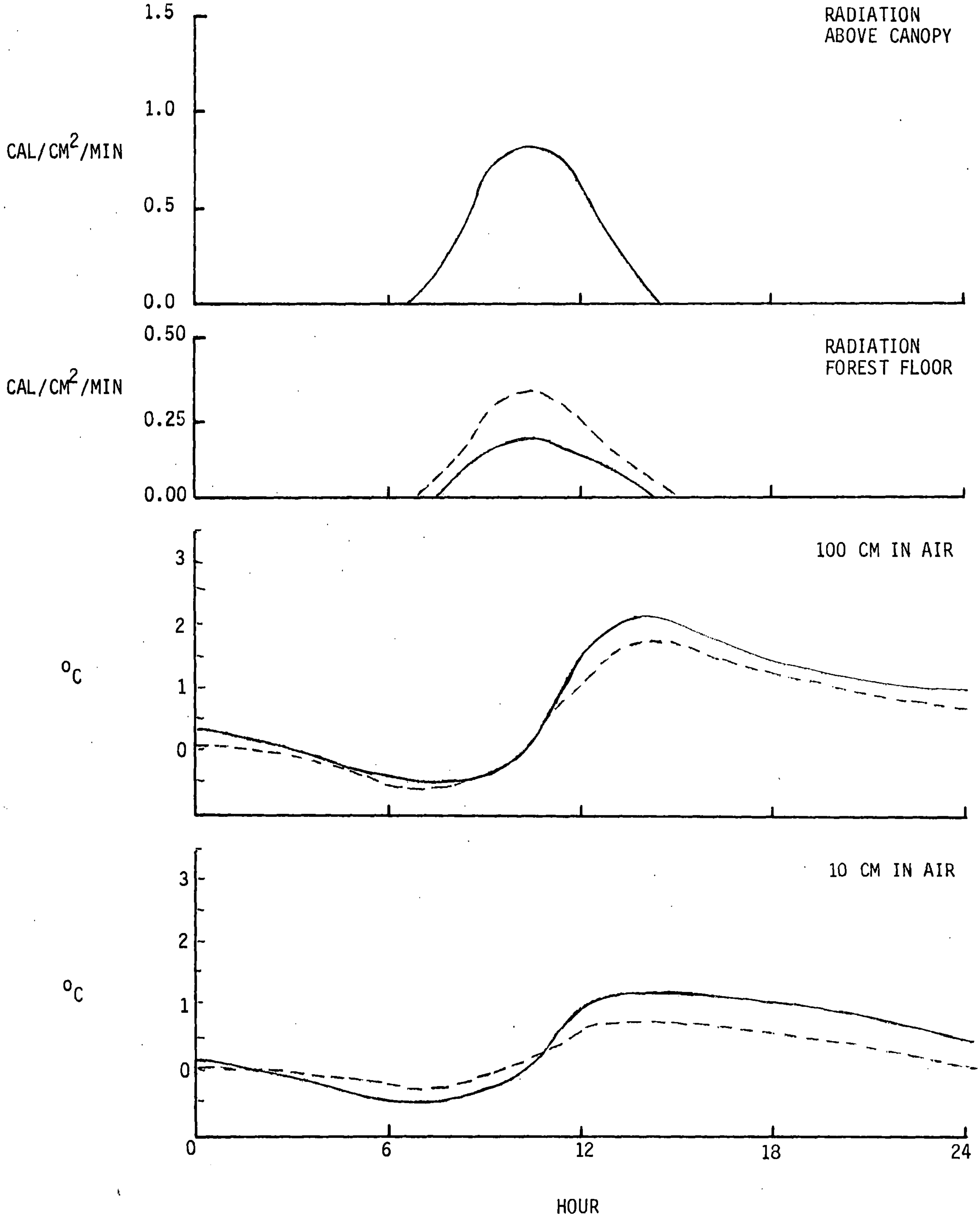
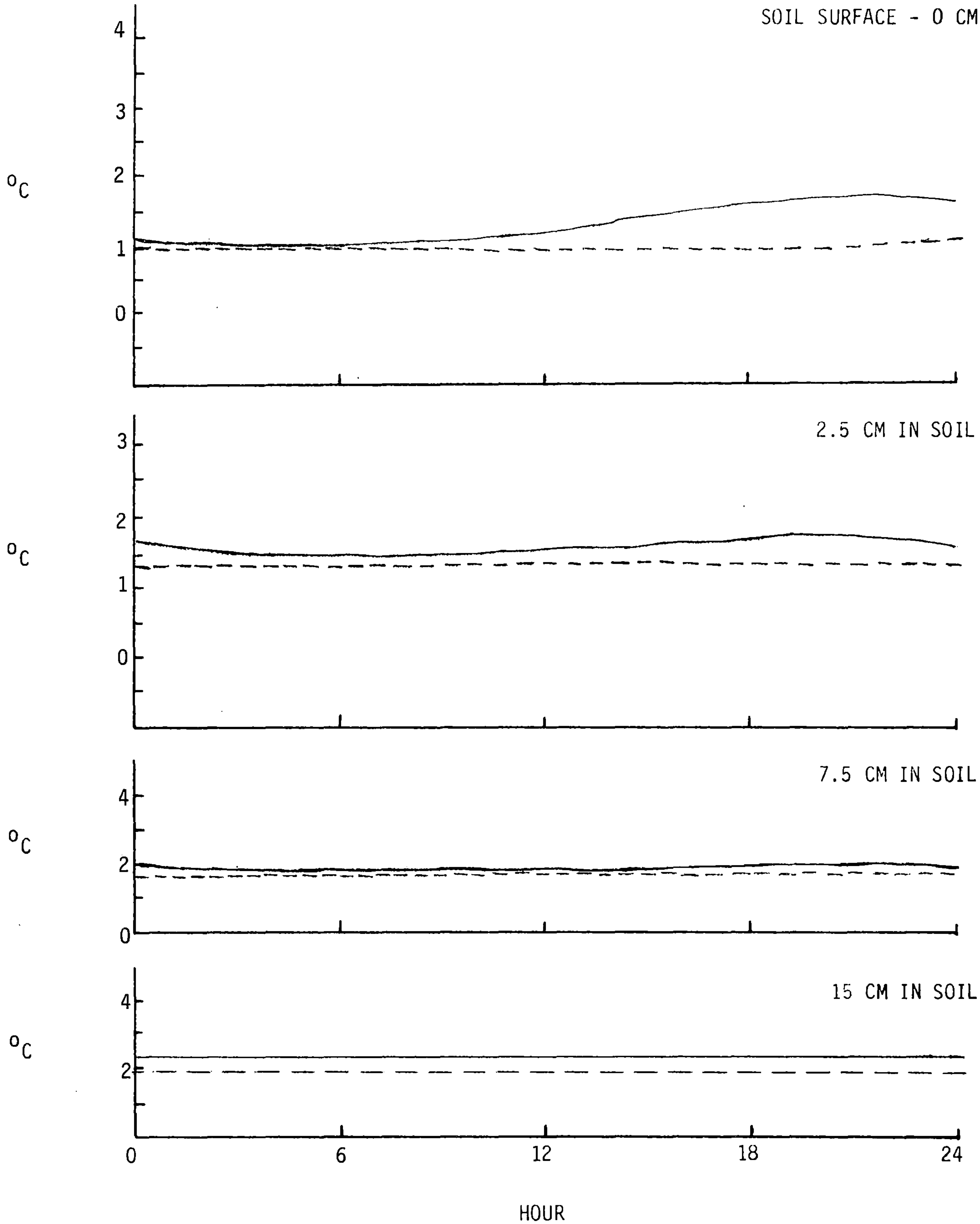



FIG. 23. AVERAGE RADIATION, AIR TEMPERATURE AND SOIL TEMPERATURE FOR CONTROL BLOCK E (——) AND DEFOLIATED BLOCK C (---) ON NOVEMBER 12, 1977.


SOIL SURFACE - 0 CM
2.5 CM IN SOIL
7.5 CM IN SOIL
15 CM IN SOIL
°C
HOUR
0
6
12
18
24

Another important observation was that air temperatures at 100 cm are warmer than the 10-cm temperatures during the winter months, but the reverse is observed during the summer months. This can be attributed to the sensible heating of the air by the soil or forest floor surface during the summer months.

One microclimate parameter not measured in our studies that may have had a significant influence was wind. In our observations of air temperatures it appears that air temperatures increased more rapidly in the morning hours in the defoliated stand, for example, Figure 11. Near mid-day the air temperature trend in the defoliated stand does not continue and the peak temperature appears to be surpressed. This supression appears to be induced by wind. Wind could have been introduced into the defoliated stand either by local mountain-valley winds or by thermal instability created by solar heating of the forest floor. We suspect that the thermal instability-induced winds have been instrumental in reducing air temperature differences between the control and defoliated stands during the summer months although we have no measurements to confirm or deny our suggestion.

Soil temperatures are shown to be warmer at all depths measured in the defoliated Block C from April through mid-July. After mid-July soil temperatures are quite similar in the treatment and control blocks until mid-October after which soil temperatures in the control block appear to be warmer. As shown for November 12, in Figure 23, soil temperatures were influenced slightly by solar radiation input to the control stand, but there was no effect on the floor of the defoliated stand.

We found that the 0-cm or litter-mineral soil interface does not appear to be a good depth to measure soil temperatures on the forest floor. Most likely, the variable thermal transmission properties of forest litter as well as defining the exact interface for sensor placement leads to large data variability. The influence of vegetation modification on soil temperature appears to be better evaluated at depths such as 2.5 cm in the mineral soil.

The measured differential in soil temperatures are possibly conservative. Increased soil moisture due to reduced evapotranspiration and the increase in forest floor depth with increased litter fall would have affected the thermal properties of the soil. Soil at higher moisture contents has both a higher heat capacity and a higher thermal conductivity, requiring a larger amount of energy input to raise soil temperatures. Although the forest floor albedo or reflectivity in the defoliated stand was lower in 1977 than in 1976 (Table 4), it was still higher than was measured in the control stand. Thus, more energy reaching the forest floor in the defoliated stand was reflected with a smaller fraction of the input going into sensible heating.

Data here supports our hypothesis that conifer defoliation by insects can have a measurable influence on soil temperature during the summer months. Soil temperature increases at our experimental site are sufficient to influence biologic activity. Since defoliation of conifers by insects is not always total removal of all needles, some relationship needs to be developed between defoliation and changes in soil temperature for a given energy input at the forest floor.

In Figure 24 we have plotted the maximum difference in soil temperature at the 2.5-cm depth as a function of that differential fraction of diffused radiation reaching the forest floor measured by the canopy photographs. There will be no linear or other correlation because of advection by wind, time differences in soil thermal properties, etc. However, the data do show that with a change in canopy diffuse radiation of 18.3 percent as measured on Block C due to defoliation, approximately 45 cal/cm$^2$/day is necessary to create a detectable 0.1$^{o}$ C change in soil temperature at the Nason Creek experimental site. If we find the percentage of 45 cal/cm$^2$/day of the total daily above-canopy radiation for specific days where soil temperature modification was observed, we can suggest the threshold defoliation level necessary to influence soil temperature (Figure 25). For some given level of solar radiation reaching the top of the forest canopy, there is a minimum level of defoliation that will affect soil temperatures. Obviously this relationship defined here is only for one area under one set of physical conditions, but it may relate to other areas of the interior Pacific Northwest. Further research and testing is needed to confirm this relationship.

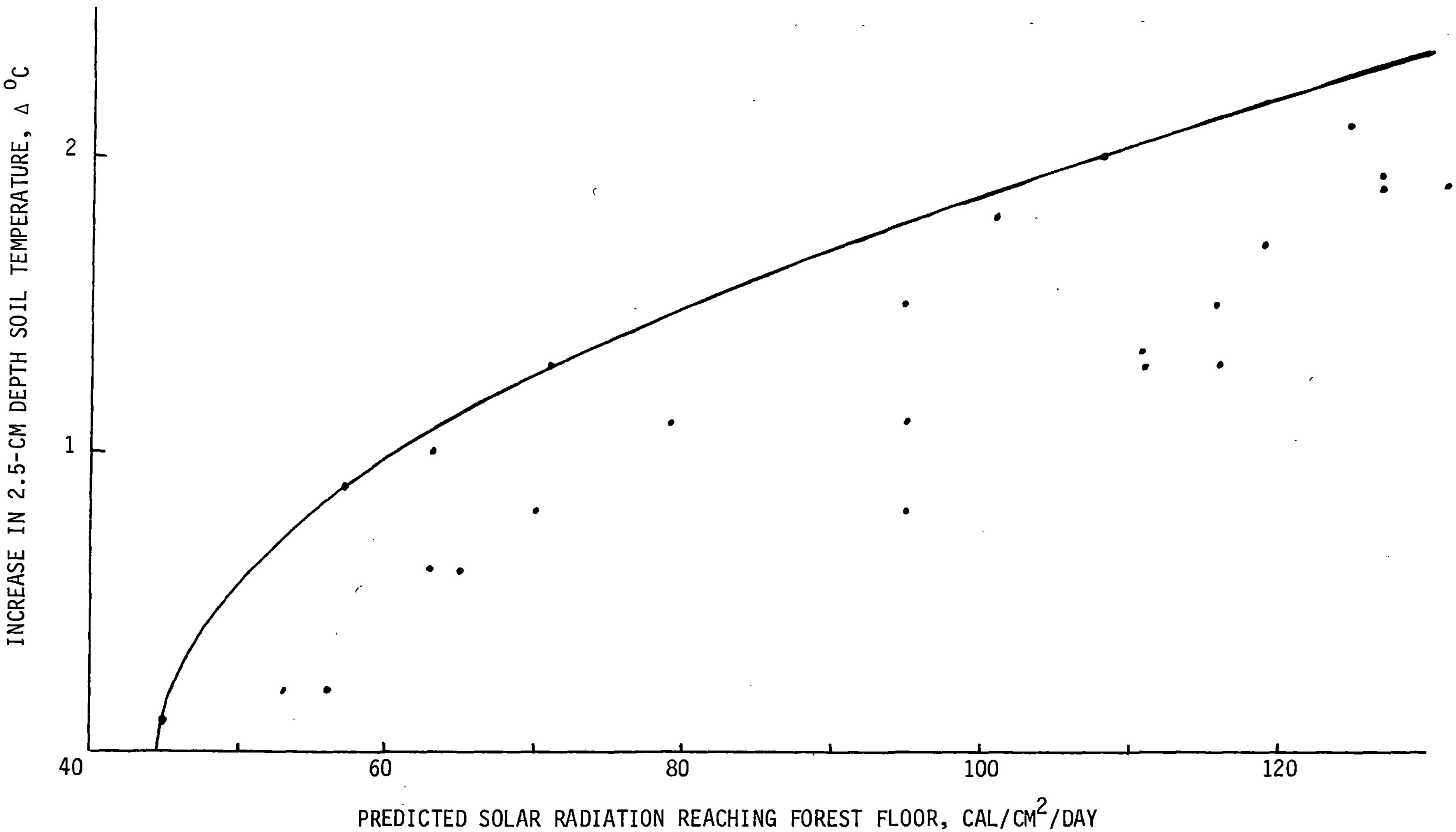



FIG. 24. INFLUENCE OF DEFOLIATION REMOVING 18.3 PERCENT OF THE CANOPY AS MEASURED BY THE HEMISPHERICAL PHOTOGRAPH METHOD ON CHANGES IN SOIL TEMPERATURES AT THE 2.5-CM DEPTH.

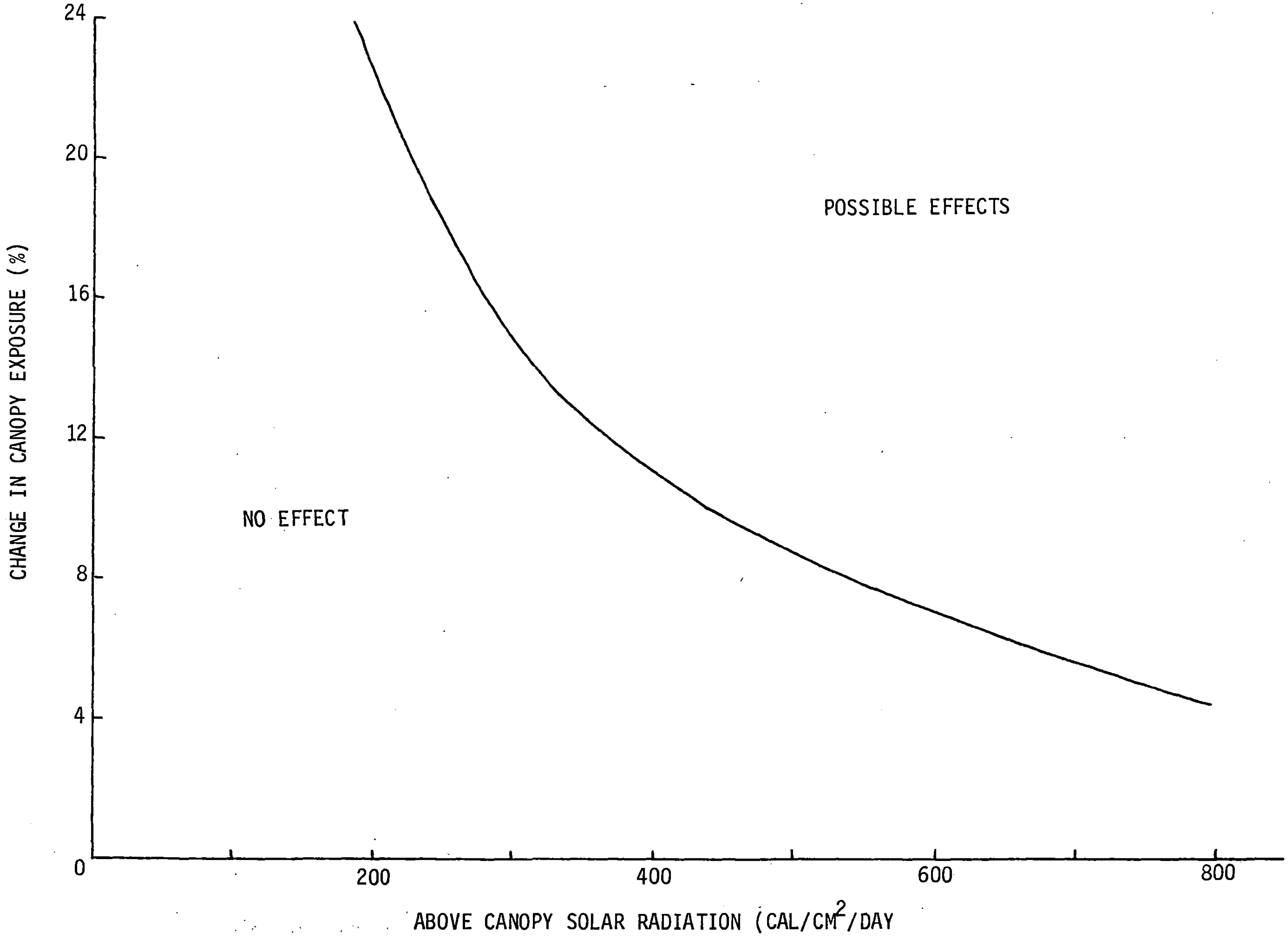



FIG. 25. THRESHOLD LEVELS OF DEFOLIATION FOR SPECIFIC SOLAR RADIATION LEVELS ABOVE THE FOREST CANOPY THAT MAY RAISE SOIL TEMPERATURE AT THE 2-5 CM DEPTH 0.1° C OR GREATER AT THE NASON CREEK EXPERIMENTAL SITE.

Soil Moisture Regimes

Average soil water contents measured during the summer of 1976 are shown in Table 15. Changes in moisture content at different depths with time are plotted in Figures 26a and 26b. In early April 1976, there was about 60 to 90 cm of snow cover on the ground. Following snowmelt in late April, the first soil moisture readings, obtained on May 5, showed the subsoil to be close to saturation. For Blocks A and B, soil moisture contents throughout the profile remained essentially the same for the months of May and June. By the end of July, one month after the first defoliation treatment, divergences between Blocks A and B were observed at the 60-, 90-, 120- and 150-cm depths. The defoliated block (Block A) had the higher average moisture content in all cases. These trends persisted until October 16, 1976, when the last moisture readings of the season were made. Statistical evidence was obtained on September 2 and on October 16 that the soil moisture contents were higher for the defoliated Block A than for Block B at the 60-, 90-, and 120-cm soil depths.

Blocks C and E appeared to have different soil moisture distribution patterns than Blocks A and B. In both May and June, Block C appeared to have higher moisture contents in the profile than Block E. This can probably by attributed to the relative locations of these two blocks. Block C is located near the bottom of the alluvial outwash plain, whereas Block E is located between Block C and the nearby hills. More water could have moved downslope into Block C, resulting in its higher early season water contents. Apparently,

Table 15. Average soil water contents at different depths for each experimental block during the summer of 1976.

| Block | Depth (cm) | Soil Water Content (% by volume) 5/5 | 5/21 | 6/1 | 6/25 | 7/8 | 7/23 | 8/13 | 9/2 | 10/16 |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 30 | 37.70 | 36.82 | 31.80 | 29.01 | 20.61 | 15.10 | 18.11 | 18.02 | 16.43 |
| | 60 | 46.00 | 43.34 | 40.08 | 36.73 | 31.30 | 28.57 | 26.20 | 25.52* | 24.07* |
| | 90 | 47.16 | 44.48 | 42.54 | 40.14 | 37.04 | 34.76 | 31.66 | 30.29* | 28.81* |
| | 120 | 48.18 | 42.60 | 41.30 | 39.03 | 38.08 | 37.43 | 34.01 | 32.49* | 30.26* |
| | 150 | 45.78 | 43.64 | 41.72 | 39.87 | 37.81 | 37.13 | 34.55 | 33.14 | 31.03* |
| B | 30 | 35.26 | 33.94 | 31.54 | 26.62 | 21.49 | 17.23 | 17.79 | 16.55 | 14.56 |
| | 60 | 44.88 | 42.72 | 40.58 | 36.20 | 29.58 | 26.04 | 23.18 | 21.93* | 19.96* |
| | 90 | 44.66 | 43.84 | 41.50 | 38.17 | 36.34 | 32.44 | 28.18 | 26.13* | 23.37* |
| | 120 | 43.64 | 42.12 | 41.12 | 38.27 | 36.74 | 34.28 | 30.35 | 27.62* | 24.62* |
| | 150 | 45.46 | 44.00 | 41.62 | 39.91 | 38.47 | 35.65 | 32.70 | 29.88 | 26.27* |
| C | 30 | 38.43 | 33.25 | 30.10 | 24.84 | 20.75 | 16.67 | 18.73 | 20.68 | 16.82 |
| | 60 | 49.83 | 39.43 | 37.00 | 31.37 | 24.32 | 21.37 | 19.74 | 20.02 | 19.22 |
| | 90 | 51.30 | 44.50* | 43.40 | 37.74 | 33.40 | 28.81 | 25.11 | 24.14 | 22.67 |
| | 120 | 55.40 | 47.50* | 45.06* | 40.19 | 37.75 | 35.19 | 32.10 | 30.85 | 28.91 |
| | 150 | | 51.15* | 51.95* | 42.77* | 40.16 | 38.94 | 37.15 | 37.01* | 34.96* |
| E | 30 | 38.78 | 35.40 | 32.45 | 26.42 | 20.65 | 16.79 | 17.68 | 16.64 | 13.98 |
| | 60 | 40.85 | 37.43 | 35.08 | 31.38 | 26.13 | 22.73 | 2.057 | 19.44 | 17.14 |
| | 90 | 44.58 | 39.30* | 37.90 | 35.42 | 32.67 | 29.43 | 25.72 | 23.14 | 19.49 |
| | 120 | 49.17 | 41.58* | 37.93* | 36.76 | 34.92 | 32.57 | 29.47 | 26.26 | 22.07 |
| | 150 | 52.30 | 44.43* | 41.33* | 39.21* | 37.31 | 35.33 | 32.87 | 29.57* | 24.32* |

* Denotes a significant difference at the 0.05 level l.s.d. comparisons made between blocks A and B and blocks C and E.

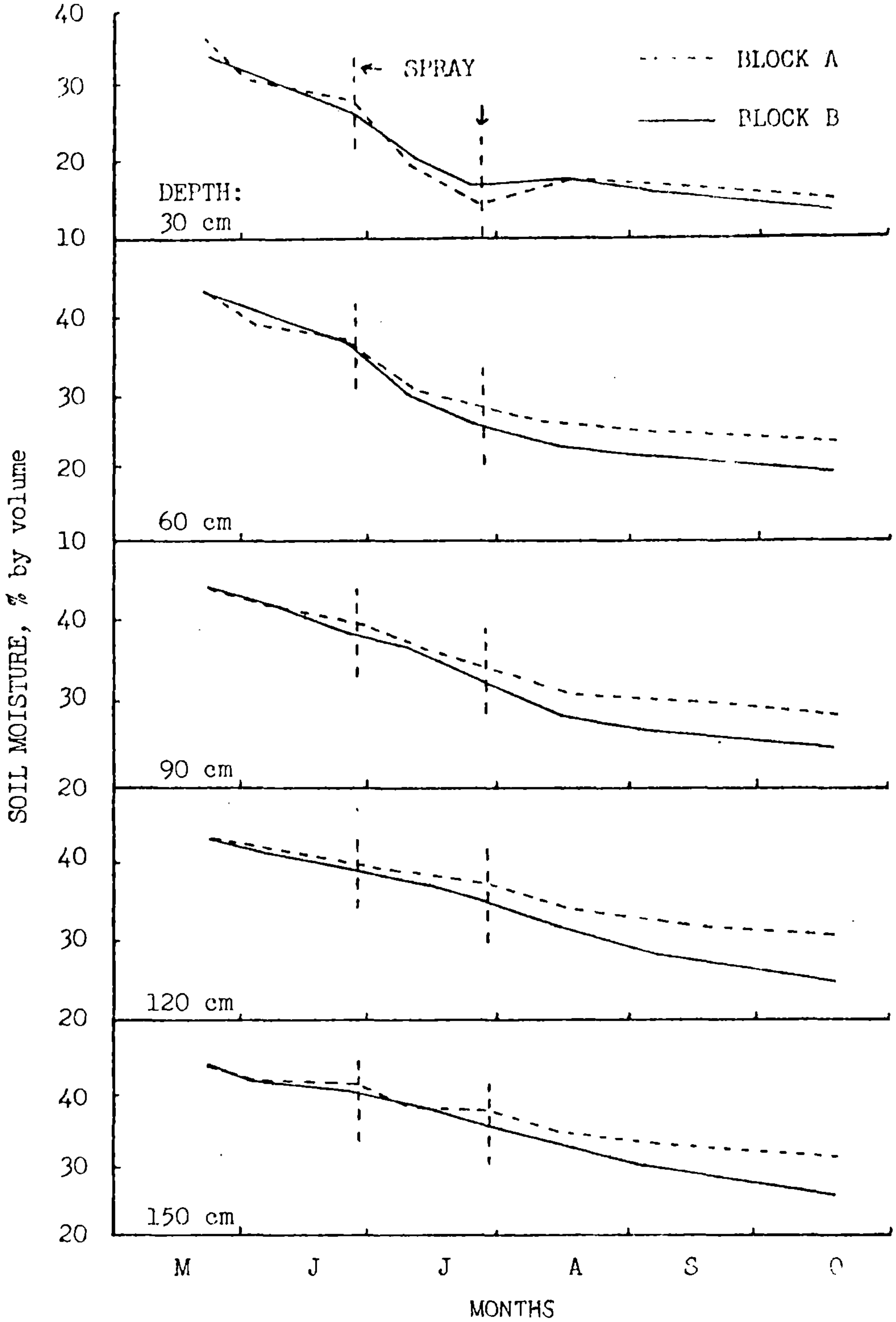



FIG. 26a. AVERAGE SOIL WATER DEPLETION PATTERNS FOR DIFFERENT SOIL DEPTHS DURING THE SUMMER OF 1976 FOR BLOCKS A AND B.

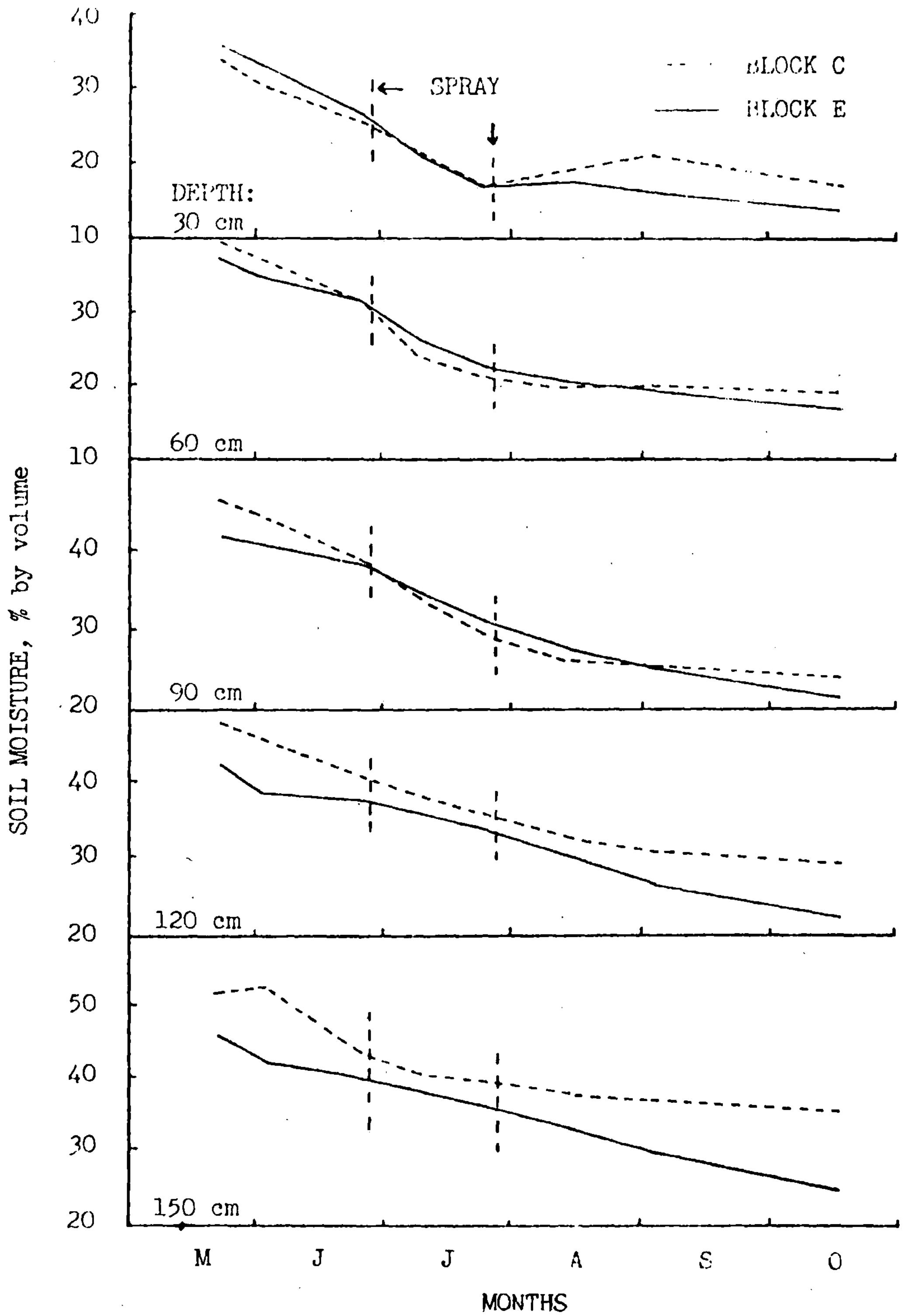



FIG. 26b. AVERAGE SOIL WATER DEPLETION PATTERNS FOR DIFFERENT SOIL DEPTHS DURING THE SUMMER OF 1976 FOR BLOCKS C AND E.

Block C had higher water depletion tendency than that of Block E. This is verified by the higher moisture contents in May, but lower moisture contents in July at both 60- and 90-cm depths, as well as by the greater differences in May and yet smaller differences in July at the 120- and 150cm depths for Block C. Defoliation reduced the high water depletion trend of Block C, resulting in higher moisture contents at the 60- and 90-cm depths, and greater differences at the 120- and 150-cm depths in September and October, when compared with Block E. Though it was not demonstrated statistically for the defoliation effect on soil moisture regimes between Blocks C and E, the general trend of the soil moisture depletion curves following defoliation also supports the hypothesis that defoliation results in higher soil moisture contents.

Data in Table 15 for the 30 cm depth show higher water contents after defoliation than existed in the control blocks. Although insufficient data are available to prove this statistically, the effect appears to be real. The increased moisture content in August was due to rainstorms. This increase at the 30-cm depth was actually higher for the defoliated blocks than for the controls. This could be due either to changes in the canopy structure, which result in reduced interception and transpiration, or to the mulching effect of the newly fallen needles.

Figure 26c shows the amount of water depleted in the 1.5-m soil mantle during the summer of 1976 based on the amount of water present in the mantle in May. The effect of defoliation on soil moisture depletion is demonstrated by the significantly smaller depletion rates (slopes of the curves) observed

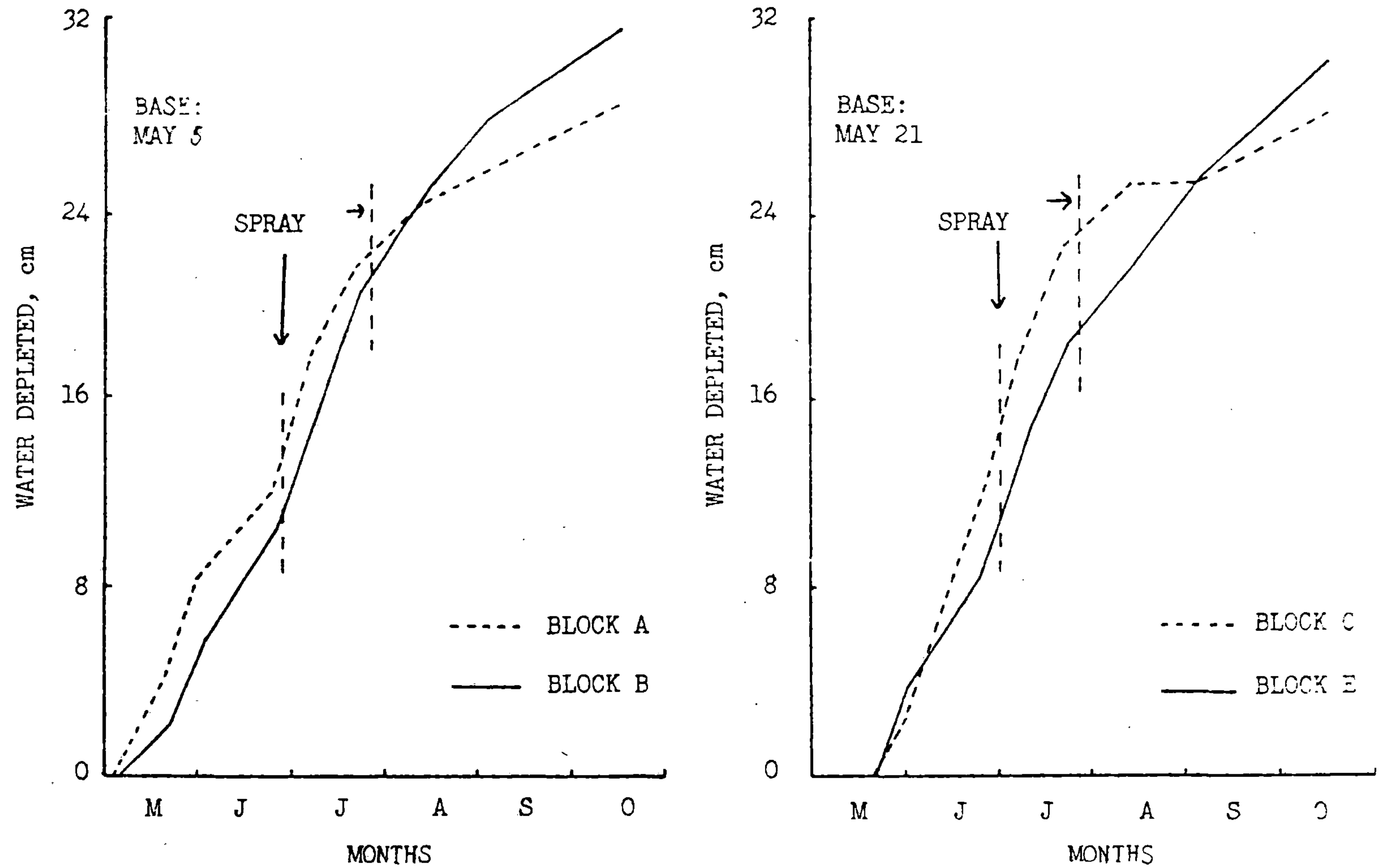



FIG. 26c. AMOUNT OF WATER DEPLETED IN THE 1.5-M SOIL MANTLE DURING THE SUMMER OF 1976.

for the defoliated blocks in August. Total soil water content of the mantle in centimeters is given in Table 8 for all dates of measurement in 1976. There appears to have been about 6.6 and 7.7 cm more water in defoliated Blocks A and C, respectively, than in control Blocks B and E on the October sampling date.

During the spring of 1977 the soil water content returned to the same levels as were monitored in the spring of 1976 in all blocks. Thus the near drought conditions that were occurring in the region did not affect soil profile water content recharge. However, the snowpack was much less and with less spring precipitation, soil moisture withdrawal by the trees was observed much earlier. In 1976 the soil profile remained near field capacity until mid-May while in 1977 soil water depletion was observed in mid-April in the control stands.

Soil water depletion during the summer of 1977 reflected the same trends as were established after the defoliation treatment in 1976. Soil water depletion was significantly less at all depths in defoliated Block A as shown in Figure 27a and Block C shown in Figure 27b. Differences in use rates between the defoliated stands and the control stands which reflect the defoliation effect on evapotranspiration were observed earlier in the shallower depths. There was no precipitation from mid-June until August 21. On August 21 significant rainfall occurred which did affect the soil water content values at the 30- and 60-cm depths of August 24. After this date soil water content values continued to rise at the 30- and 60-cm depths through November 2, the last day of sampling. This reflected further precipitation as shown in Table 17. Soil water depletion remained near constant or increased slightly at the lower depths until November.

Table 16. Water contents in the upper 1.5-meter soil mantle in 1976.

| | Water Content (cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Block | 5/21 | 6/01 | 6/25 | 7/08 | 7/23 | 8/13 | 9/02 | 10/16 |
| A | 63.3 | 59.2 | 55.4 | 49.5 | 45.9 | 43.4 | 42.0 | 39.2 |
| B | 62.0 | 58.0 | 53.8 | 48.8 | 43.7 | 39.7 | 36.6 | 32.6 |
| C | 64.7 | 62.3 | 53.1 | 46.9 | 42.3 | 39.8 | 39.8 | 36.8 |
| E | 59.4 | 55.7 | 50.8 | 45.5 | 41.1 | 37.9 | 34.5 | 29.1 |

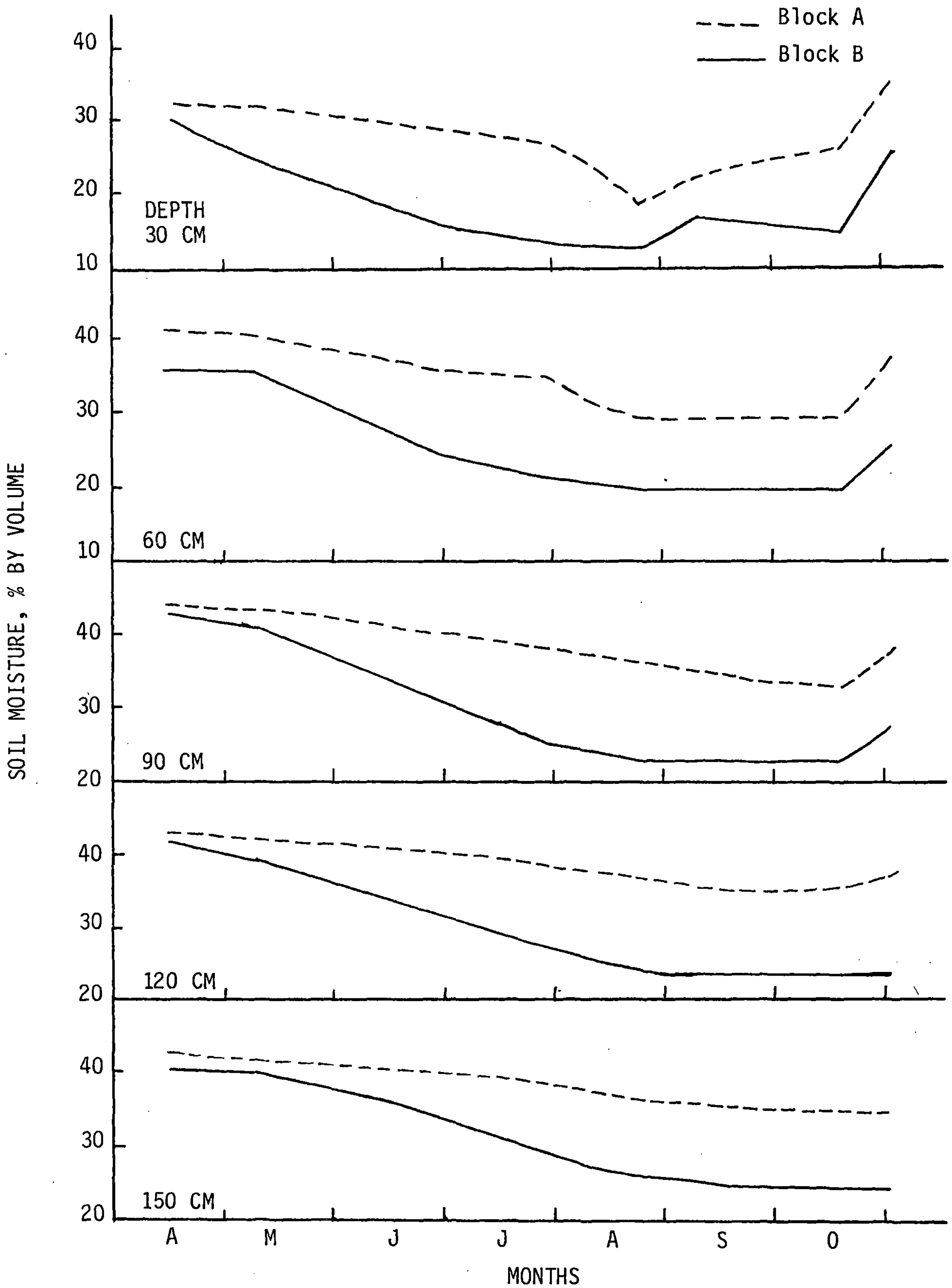



FIG. 27a. AVERAGE SOIL WATER DEPLETION PATTERNS FOR DIFFERENT SOIL DEPTHS DURING 1977 FOR BLOCKS A AND B.

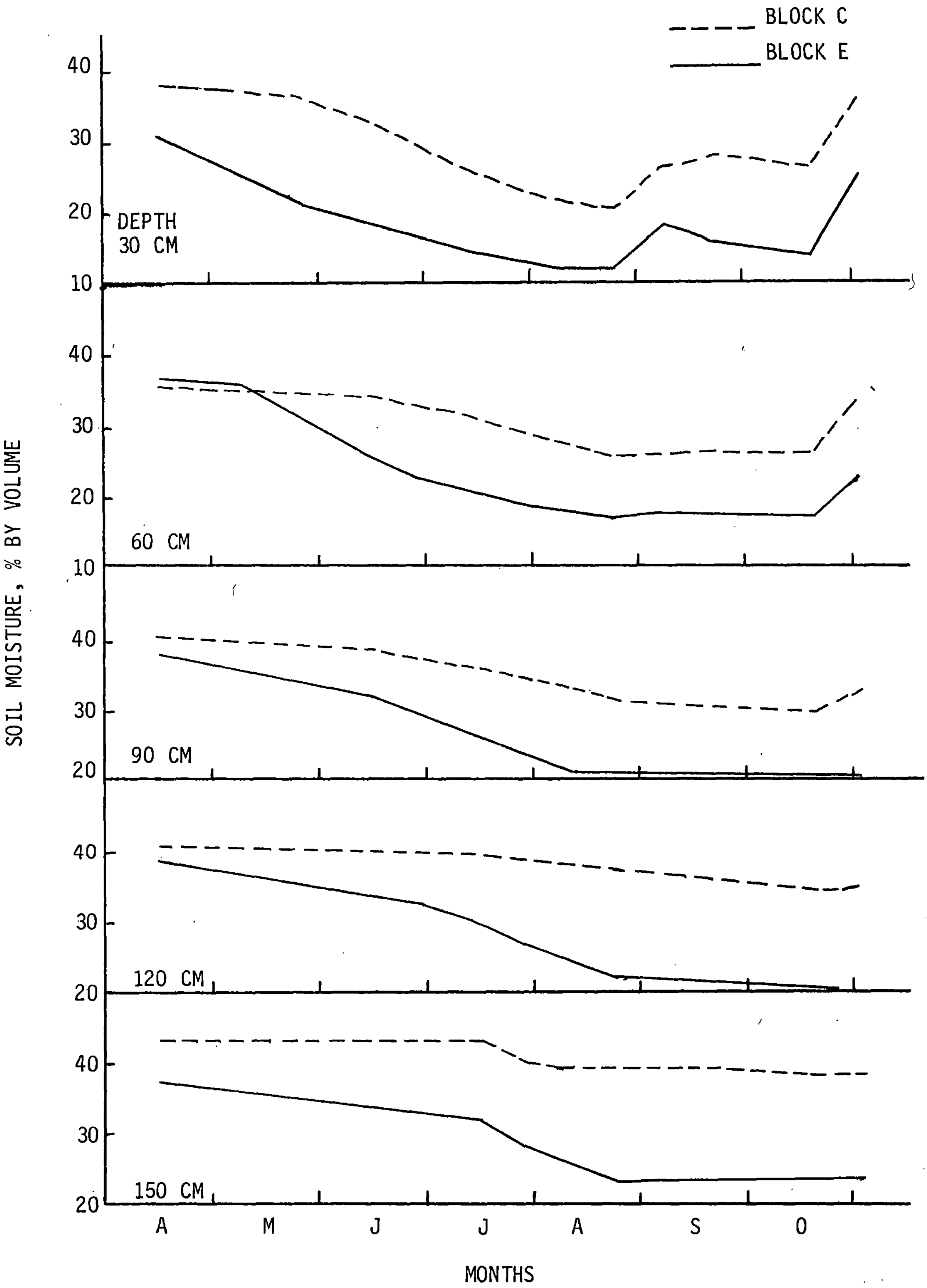



FIG. 27b. AVERAGE SOIL WATER DEPLETION PATTERNS FOR DIFFERENT SOIL DEPTHS DURING 1977 FOR BLOCKS C AND E.

The amount of water depleted in the upper 1.5 m of the soil mantle during 1977 is shown for all blocks in Figure 27c. This depletion is calculated from the water content values shown in Table 18. Soil water depletion appeared to begin in both the defoliated Block A and control Block B near the same time in April although at a reduced rate in the defoliated block. Observations of the soil water content values showed that depletion in Block C began nearly a month later than in the control Block E. This difference may be due to a small influx of transient groundwater from outside the plot during the spring months that was explained earlier.

It is interesting to note that the rate of soil moisture depletion from the first time observed in April through mid-August was very similar in the control plots in 1977 as it was in 1976. Thus, we might conclude that the stand water use characteristics were very similar in 1976 and 1977. However, after the early fall rains started on August 22, 1977, the soil mantle water content was not further depleted as it was in the very dry period of late August, September, and early October of 1976. Maximum difference in soil water depletion levels were 12.1 cm between Blocks A and B and 14.5 cm between Blocks C and E. This difference in water depletion between the two blocks could be partially explained by the 9-percent greater canopy exposure in Block C than Block A as measured by the hemispherical photographic method, indicating a higher level of defoliation in Block C. Since the soil mantle appears to recharge each year to field capacity, this 12.1 to 14.5 cm of soil water should be available to increase streamflow. The effects on streamflow should also appear earlier as it will take less precipitation to bring the soil mantle in the defoliated area to field capacity and allowing the excess water to provide for streamflow.

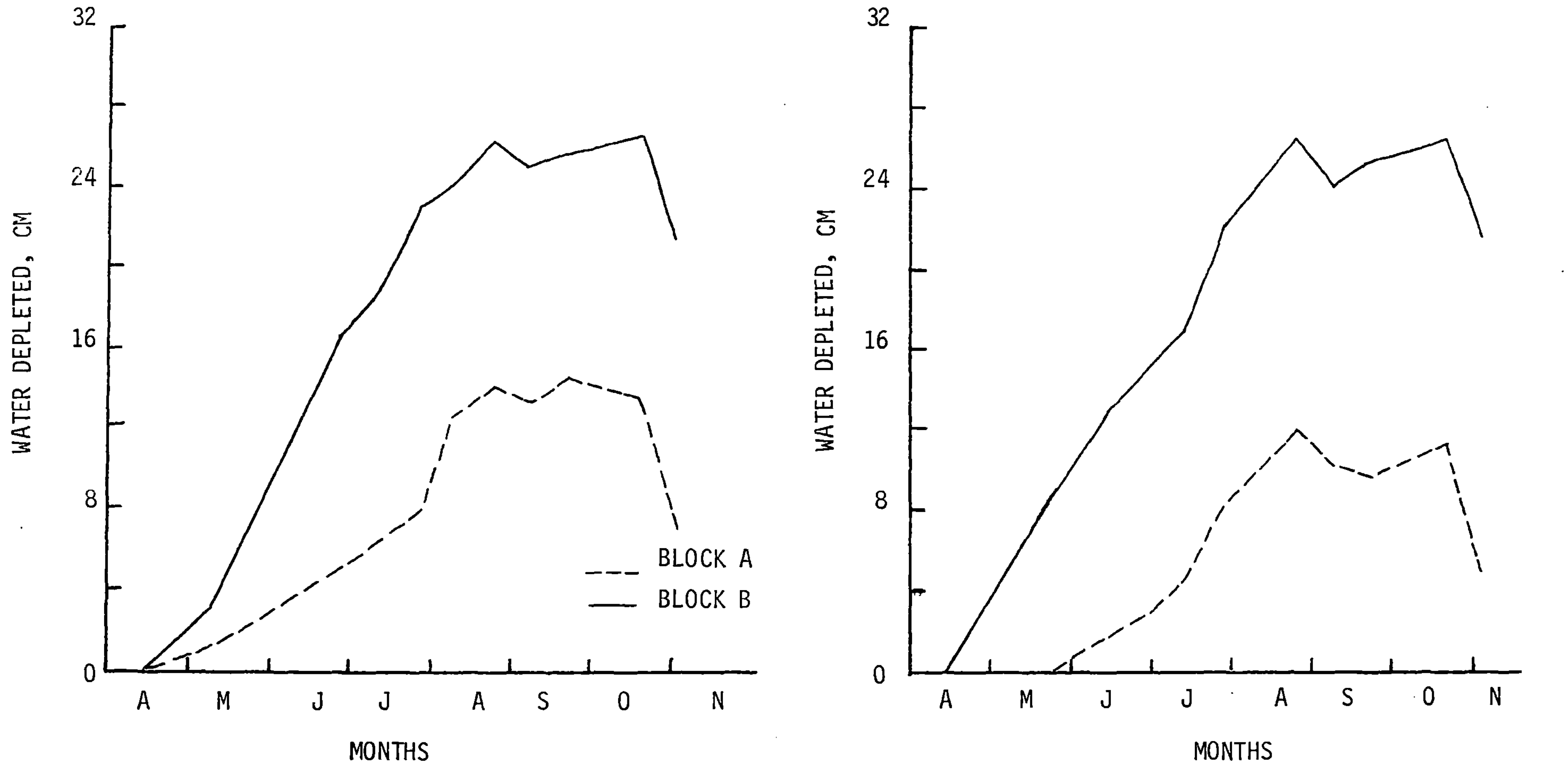



FIG. 27c. AMOUNT OF WATER DEPLETED IN THE UPPER 1.5 M SOIL MANTLE DURING THE SUMMER OF 1977.

Table 17. Monthly precipitation at the Nason Creek experimental site.

| | Date | Precipitation (cm) | | Date | Precipitation (cm) |
|---|---|---|---|---|---|
| 1976 | -- | | 1977 | Jan. | 5.3 |
| | -- | | | Feb. | 9.1 |
| | -- | | | Mar. | 8.3 |
| | April | 3.9 | | April | 1.6 |
| | May | 2.4 | | May | 2.8 |
| | June | 0.9 | | June | 2.0 |
| | July | 0.9 | | July | 0 |
| | Aug. | 4.7 | | Aug. | 2.8 |
| | Sept. | 0.3 | | Sept. | 4.9 |
| | Oct. | 5.5 | | Oct. | 3.4 |
| | Nov. | 6.4 | | | |
| | Dec. | 9.3 | | | |

Table 18. Water content in the upper 1.5-meter soil mantle in 1977.

| Block | 4/16 | 5/9 | 5/26 | 6/15 | 6/29 | 7/13 | 7/27 |
|---|---|---|---|---|---|---|---|
| A | 61.0 | 59.9 | 58.3 | 57.3 | 55.7 | 54.5 | 53.2 |
| B | 57.5 | 54.0 | 50.2 | 46.9 | 40.6 | 38.9 | 34.5 |
| C | 56.9 | -- | 57.1 | 55.0 | 54.2 | 52.2 | 48.7 |
| E | 54.1 | -- | 45.4 | 43.4 | 39.2 | 37.1 | 32.6 |

| Block | 8/10 | 8/24 | 9/7 | 9/21 | 10/19 | 11/2 |
|---|---|---|---|---|---|---|
| A | 50.2 | 46.9 | 47.7 | 46.6 | 47.3 | 54.0 |
| B | 33.2 | 31.3 | 32.5 | 31.7 | 31.0 | 37.7 |
| C | 47.4 | 45.1 | 46.8 | 47.3 | 45.7 | 52.0 |
| E | 30.1 | 27.6 | 29.8 | 28.8 | 27.5 | 32.2 |

In regions where a dry summer season prevails the reduced water use by defoliated stands may also be ecologically important. High profile moisture contents could reduce tree water stress late in the growing season. Microbial activity, including forest floor decomposition, could be enhanced under more mesic conditions.

Soil Physical Analyses

Soil bulk density increased at all sites with increasing depth in the profile as shown in Table 19. These bulk densities indicate that there is not a significant influence of volcanic ash at this site, as is prevalent throughout the Cascade Range. The presence of earthworms at this site not formerly found on soils with high volcanic ash content, would be further evidence of this fact.

Soil texture in the upper 30 cm as shown in Table 20 was quite uniform within each replication. The C and E block replication appeared to have a slightly higher sand content. This difference in sand content could be influenced by the position of the blocks on the glacial outwash terrace.

Bioassay Analyses

Although results of the bioassay analyses for samples collected in 1977 are not yet available, no significant trends were noted during 1975 and 1976 (Table 23). Since there were no consistent significant changes in soil nutrient concentrations observed during this period, significant changes in bioassay results were not expected. The average bioassay results for Block A in the October 1975 samples are extremely low. No reason can be given for such behavior because individual samples of the same soils agreed closely in all measured soil nutrient parameters.

Table 19. Bulk densities at the experimental site.

| Depth (cm) | Bulk Density ($g/cm^3$) |
|---|---|
| 0-3 | 0.95 |
| 3-7.5 | 1.09 |
| 7.5-30 | 1.23 |
| 60 | 1.47 |
| 90 | 1.56 |

Table 20. Soil texture at the experimental site.

| Block | Depth (cm) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|
| A | 0-3 | 49.2 | 38.0 | 12.8 |
| | 3-7.5 | 48.2 | 37.0 | 12.8 |
| | 7.5-15 | 50.2 | 35.0 | 14.8 |
| | 15-30 | 42.2 | 41.0 | 16.8 |
| B | 0-3 | 52.0 | 36.0 | 12.0 |
| | 3-7.5 | 52.0 | 36.0 | 12.0 |
| | 7.5-15 | 54.0 | 34.0 | 12.0 |
| | 15-30 | 52.1 | 35.0 | 12.9 |
| C | 0-3 | 53.2 | 36.0 | 10.8 |
| | 3-7.5 | 57.2 | 32.0 | 10.8 |
| | 7.5-15 | 59.2 | 28.0 | 12.8 |
| | 15-30 | 59.2 | 30.0 | 10.8 |
| E | 0-3 | 54.4 | 35.0 | 10.6 |
| | 3-7.5 | 56.4 | 32.0 | 11.6 |
| | 7.5-15 | 55.4 | 34.0 | 10.6 |
| | 15-30 | 55.4 | 33.0 | 11.6 |

Nutrient Flux Studies

To determine the effects of defoliation on the flux of nutrients to the forest floor, litter fall was sampled at 6-month intervals with 1-m-sq traps from November 1, 1975, through November 1, 1977. The amount of litter collected adjusted to the kg/ha base is shown in Table 21. Nutrient concentrations determined by Brown (1977) were used to calculate the total nitrogen, and available (primarily soluble and exchangeable) phosphorus, potassium, calcium, and magnesium. It is generally considered that a mature stand of Douglas-fir will use nearly 20 kg/ha of nitrogen. It is also interesting to note that our control blocks are returning to the forest floor nearly 20 kg/ha of total nitrogen in the form of needles and small branches. Thus, it appears that our experimental stand is not seriously nitrogen-deficient and that growth is most likely affected more by other factors such as climate than by nutrient availability.

Defoliation has a major influence on the return of nutrients to the forest floor from the stand. During the defoliation period almost 10 times as much nitrogen as well as other nutrients were returned to the forest floor. Although the rate of availability of these nutrients to the vegetation through forest floor/organic matter decomposition and leaching is unknown at this time, the additional nutrients have to have a significant effect on plant nutrition relationships in the future. A decrease in the nutrient flux after defoliation because of the reduction in annual needles casting may have a negative effect on plant nutrient relationships sometime in the future. However, our most recent data indicate that the decrease in nutrient flux through needle fall may be partially compensated by the increase in the fall of small branches.

Table 21. Litter fall and nutrient concentration at the Nason Creek experimental site.

| Block | Period | Litter Weight | Components: Needles | Components: Branches | Nutrients*: N | Nutrients*: P | Nutrients*: K | Nutrients*: Ca | Nutrients*: Mg |
|---|---|---|---|---|---|---|---|---|---|
| | | kg/ha | % | % | kg/ha | kg/ha | kg/ha | kg/ha | kg/ha |
| A | Nov. 75-Apr. 76 | 1,071 | 60.0 | 40.0 | 6.1 | 1.5 | 5.1 | 8.0 | 0.9 |
| | **May 76-Oct. 76 | 15,633 | 98.6 | 1.4 | 116.3 | 30.8 | 59.1 | 121.8 | 17.0 |
| | Nov. 76-Apr. 77 | 1,588 | 66.7 | 33.4 | 9.6 | 2.4 | 8.0 | 12.0 | 0.9 |
| | May 77-Oct. 77 | 1,525 | 41.7 | 58.3 | 7.5 | 1.8 | 6.3 | 11.2 | 1.0 |
| B | Nov. 75-Apr. 76 | 995 | 57.0 | 43.0 | 5.6 | 1.4 | 4.7 | 7.4 | 0.8 |
| | May 76-Oct. 76 | 1,737 | 90.6 | 9.4 | 12.2 | 3.2 | 9.8 | 13.4 | 1.8 |
| | Nov. 76-Apr. 77 | 885 | 69.0 | 31.0 | 5.4 | 1.4 | 4.5 | 6.7 | 0.8 |
| | May 77-Oct. 77 | 3,860 | 69.3 | 30.9 | 23.8 | 6.1 | 19.8 | 29.2 | 3.4 |
| C | Nov. 75-Apr. 76 | 1,141 | 59.3 | 40.7 | 6.5 | 1.6 | 5.5 | 8.5 | 0.9 |
| | **May 76-Oct. 76 | 16,718 | 96.9 | 3.1 | 123.1 | 32.7 | 101.8 | 130.0 | 18.0 |
| | Nov. 76-Apr. 77 | 1,663 | 58.1 | 41.9 | 9.4 | 2.3 | 7.9 | 12.4 | 1.3 |
| | May 77-Oct. 77 | 2,22[illegible] | 50.0 | 50.0 | 11.8 | 2.9 | 9.9 | 16.5 | 1.7 |

Table 21. Litter fall and nutrient concentration at the Nason Creek experimental site (continued)

| Block | Period | Litter Weight | Components Needles | Components Branches | Nutrients* N | Nutrients* P | Nutrients* K | Nutrients* Ca | Nutrients* Mg |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | - - - - - - - - - | - - kg/ha - - | - - - - - - - - - | | |
| E | Nov. 75-Apr. 76 | 1,268 | 48.7 | 51.3 | 6.7 | 1.6 | 5.6 | 9.4 | 0.9 |
| | May 76-Oct. 76 | 1,223 | 90.6 | 9.4 | 15.7 | 4.1 | 13.0 | 17.2 | 2.3 |
| | Nov. 76-Apr. 77 | 1,505 | 39.5 | 60.5 | 7.3 | 1.7 | 6.1 | 11.0 | 1.0 |
| | May 77-Oct. 77 | 3,348 | 35.0 | 65.0 | 15.5 | 3.7 | 13.1 | 24.4 | 2.2 |

| *Average nutrient concentrations (Brown, 1977) | % | % | % | % | % |
|---|---|---|---|---|---|
| Needles | 0.75 | 0.20 | 0.62 | 0.78 | 0.11 |
| Branches | 0.31 | 0.06 | 0.27 | 0.70 | 0.04 |

**Period of defoliation

Table 22. Tussock moth frass analyses.

| Component | ppm | | | | |
|---|---|---|---|---|---|
| | Total N | P | K | Ca | Mg |
| Needles | 10,435 | 890 | 3,947 | 7,254 | 1,724 |
| Excrement | 4,787 | 469 | 3,596 | 11,619 | 1,915 |

Table 23. Average bioassay results with Douglas-fir seedlings.

| | g/pot | | | |
|---|---|---|---|---|
| Block | August 1975 | October 1975 | May 1976 | October 1976 |
| A | 2.19 | 1.32 | 1.36 | 1.80 |
| B | 1.64 | 1.85 | 1.26 | 1.61 |
| C | 2.01 | 2.21 | 1.68 | 1.83 |
| E | 1.49 | 1.73 | 1.50 | 1.55 |

## Forest Floor Nutrient Distributions

The forest floor is the component of the forest ecosystem which should be first affected by forest defoliation. Average litterfall from May 1 to November 1 of 1976, as reflected by litter trap measurements, was 16 t/ha and 2 t/ha for the defoliated and control blocks, respectively. With an average predefoliation forest floor weight of 45 t/a (Appendix Table B2), it can be seen that post defoliation litterfall increased the forest floor weight by an average of nearly 35 percent. Both the weight and the nutrient content of the defoliated needles were factors to be dealt with in subsequent forest floor analyses for the site.

### Calcium

The basis on which concentrations are expressed is an important consideration when dealing with data for forest floor nutrient contents. It appears from Figure 28, for example, that the forest floor of Block E contained approximately twice as much calcium as did that of the other three blocks in August of 1975. When results were compared on a concentration (ppm) basis, however (Figure 29), it was evident that forest floor from Block E actually contained a smaller concentration of calcium than did two of the other three blocks. The reversed trend in Figure 28 can be attributed to variability in forest floor weights (Figure 30), for the Block E forest floor samples in August of 1975 included five samples of extremely high total weight (e.g., partially buried and decomposing logs). Samples containing woody material subsequently were excluded from the averages (represented in Figures 32 to 36) for forest floor nutrient

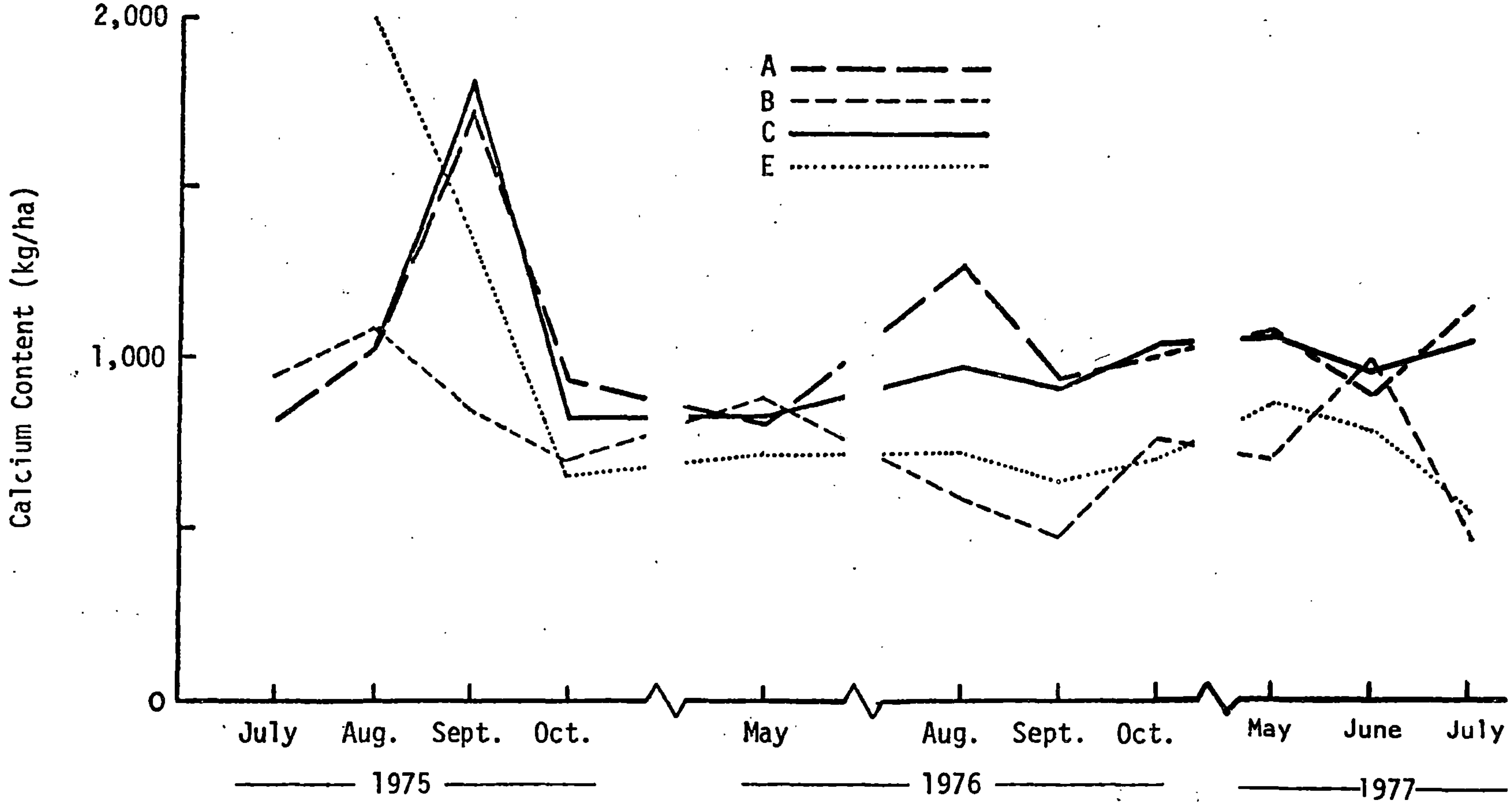



Figure 28. Nonadjusted Forest Floor Calcium Contents

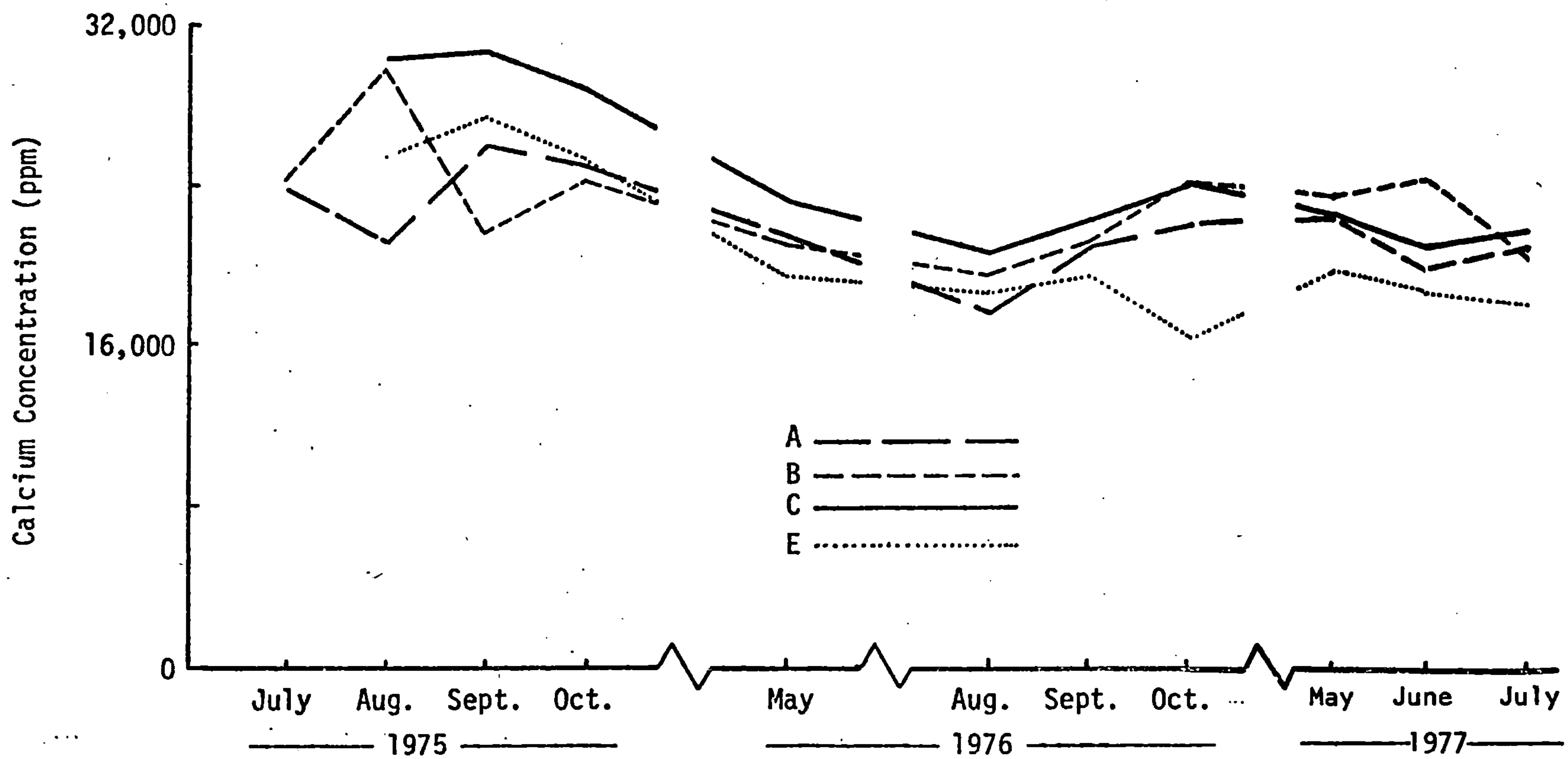



Figure 29. Forest Floor Calcium Concentrations

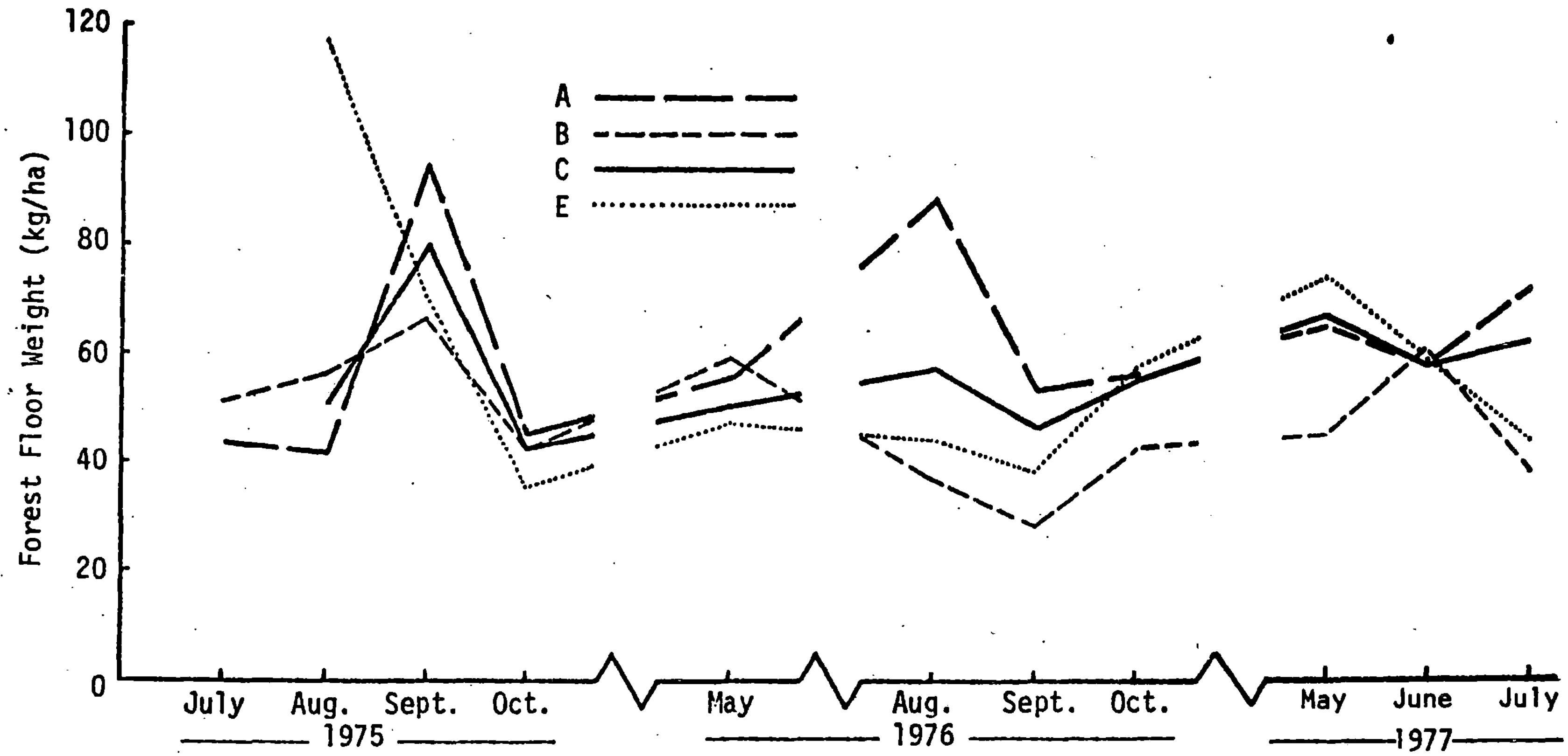



Figure 30. Nonadjusted Forest Floor Weights

levels, although they were included in the overall statistical analysis (Appendix Tables B3 to B12). Adjustment for decomposing woody materials resulted in much less variability in forest floor weights, as can be seen from Figure 31. Following defoliation, adjusted forest floor weights on blocks A and C averaged 18 t/ha greater than that on blocks B and E (Figure 31 and Appendix Table B2). This compared closely with the 16 t/ha figure determined by collecting litter on litter traps located in each experimental block.

As is evident in Figure 32, forest floors of both treatment blocks (A and C) showed increased forest floor calcium contents in late 1976 and in 1977, following defoliation. Average post-defoliation calcium content of blocks A and C was 970 kg/ha, while that of blocks B and E averaged 630 kg/ha. On a concentration basis, however, the average calcium concentration of block A actually was generally somewhat lower than that of block B (Appendix Table B4). Data for blocks C and E,on the other hand, followed the same general trend whether expressed on a concentration basis or a total content (kg/ha) basis. The greater ambiguity when data were expressed on a concentration basis suggests that calcium leaches only slowly from forest floor (litter) materials after they have been deposited. The relative constancy of forest floor calcium contents for blocks A and C following defoliation supports this postulate. Hence, the calcium of defoliated areas would tend to remain associated with the forest floor, and would not contribute to short-term nutrient fluxes of the system. The relatively large soil contents of this element would tend to minimize the effects of such short-term inaccessibility in terms of possible nutrient deficiencies at the site.

The tables of Appendix B present unadjusted forest floor nutrient contents and concentrations, as well as analysis of variance F values

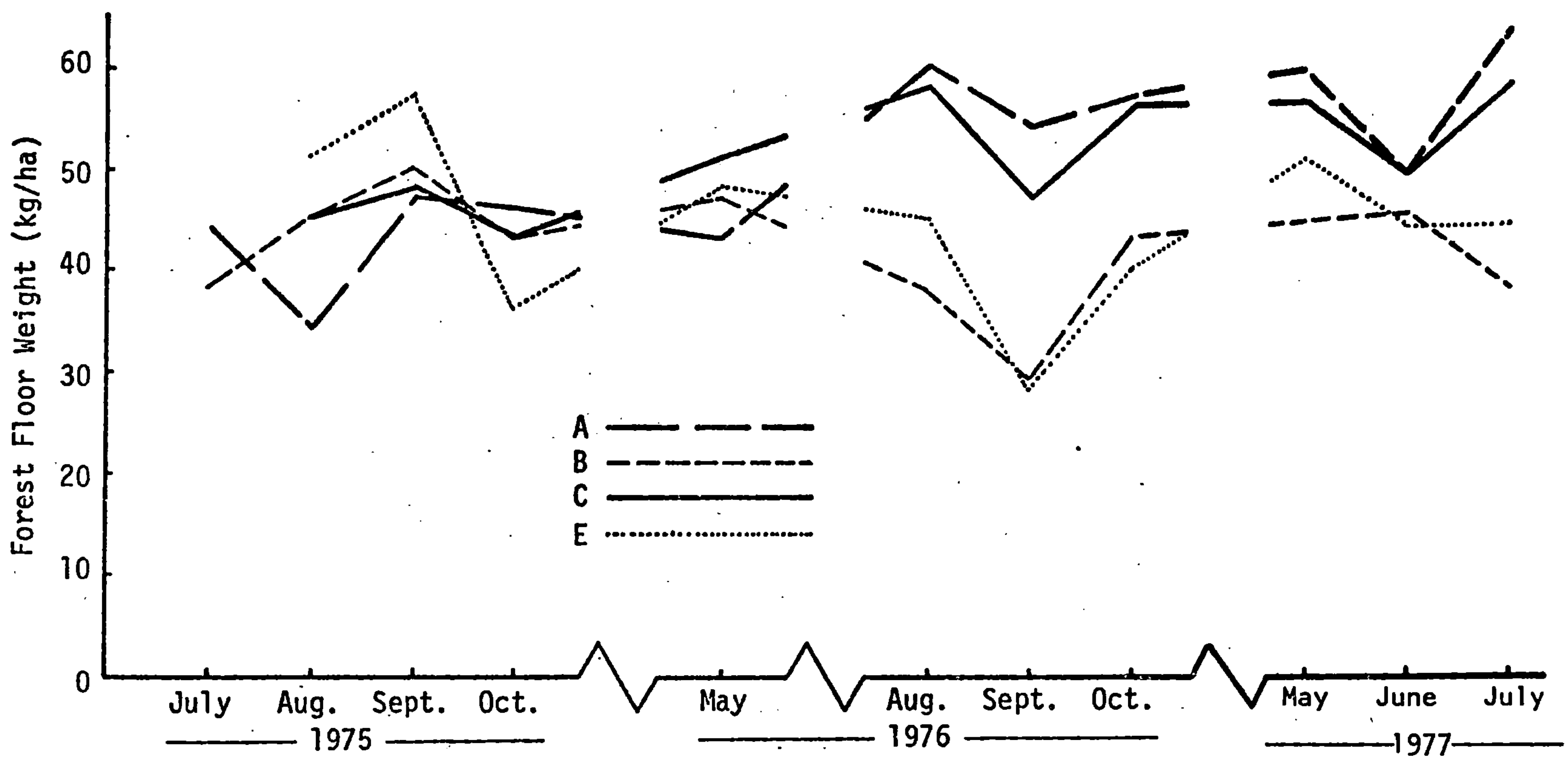



Figure 31. Adjusted Forest Floor Weights

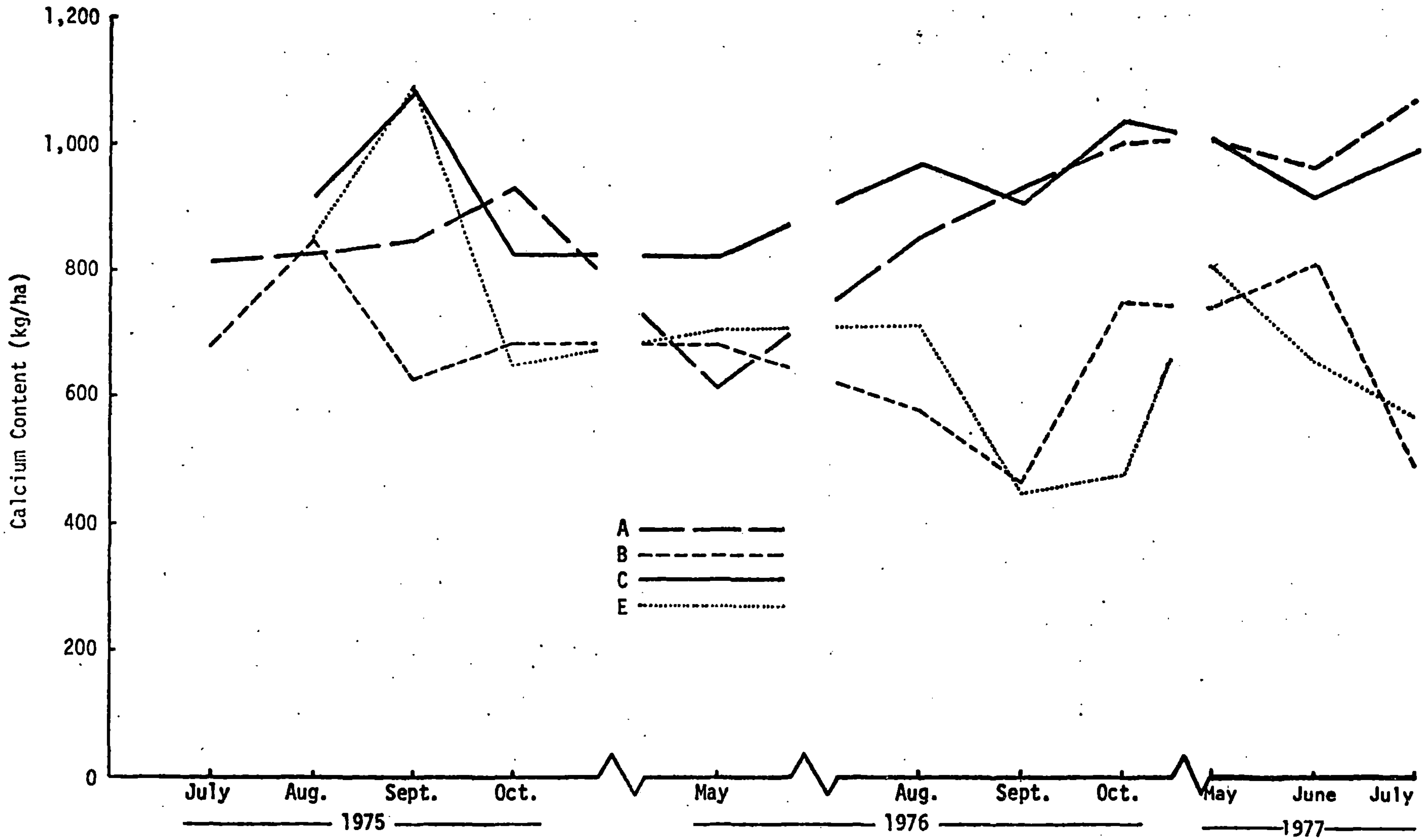



Figure 32. Adjusted Forest Floor Calcium Contents

and Tukey multiple-range values (Steel and Torrie, 1960), in order to facilitate comparisons of reported means. The Tukey test, though similar to Duncan's multiple-range test, is a less stringent procedure. Hence, if statistically significant differences were not found with the Tukey procedure, they would not be found with the Duncan test either. The Tukey test, though less widely-used than the Duncan test, was compatible with the desk-top computer used for data storage and analysis. The more complicated Duncan test, when coupled with the internal capacity required for data storage and manipulation and for sequencing through the combinations of data sets to be analyzed, exceeded the available program and storage capacity of this particular computer. Both sets of statistical values are reported at the 5 percent significance level.

For comparison of means at different times within a given block, F-test values must be greater than 2.1 for blocks A and B, and greater than 2.2 for blocks C and E, to indicate significant differences within the set of means. For comparison of means for different blocks at the _same_ time, means are significantly different at the 5 percent level only when reported F-test values are greater than 2.8. If any two means in the same row or column are different by more than the Tukey value for that row or column, the means are significantly different at the 5 percent level. Since the analysis of variance and Tukey procedures are based on different principles, slight discrepancies occur. Hence, there is always a possibility that one test may indicate that a significant difference exists, whereas the other does not. Statistical information from the Appendix is summarized in Tables 24 and 25, which show significant differences with respect to calcium only for forest floor calcium _content_ (and not for forest floor calcium _concentration_), and even then only for one pair of blocks in only two of the months following defoliation.

Table 24. Summary of Statistical Results--
Postdefoliation Forest Floor Nutrient Contents

| Comparison | Ca | Mg | K | P | N |
|---|---|---|---|---|---|
| A vs B | **[1] | ** | ***** | **** | *** |
| C vs E | 0[2] | 0 | ****** | * | 0 |

[1]The number of asterisks refers to the number of months following defoliation in which a statistical significance existed at the 5 percent level.

[2]A "0" indicates no significant differences at the 5 percent level.

Though average calcium contents of forest floor samples from the defoliated blocks were consistently higher than those from the corresponding control blocks, sample variability even in this relatively uniform forested area was so great that the trend generally was not statistically significant. Significance undoubtedly would have been demonstrable in more cases if the Appendix values had been adjusted for the presence of decomposing logs, as the data for the figures were, but this was judged improper. Site selection (on a rather uniform bench relatively free of down vegetation) and plot placement (to avoid trees, brush, etc.) had already compromised the degree to which the data were truly representative of sites in the intermountain region, and further data adjustment could not be superimposed in good conscience before testing the data for statistical significance.

## Magnesium

Forest floor magnesium followed the same general trend as did forest floor calcium. Appendix Table B5 and Figure 33 indicate that defoliated blocks A and C showed an increase in magnesium content (kg/ha) following defoliation when compared with the respective control blocks, B and E. These differences were rarely significant statistically, however (Table 24).

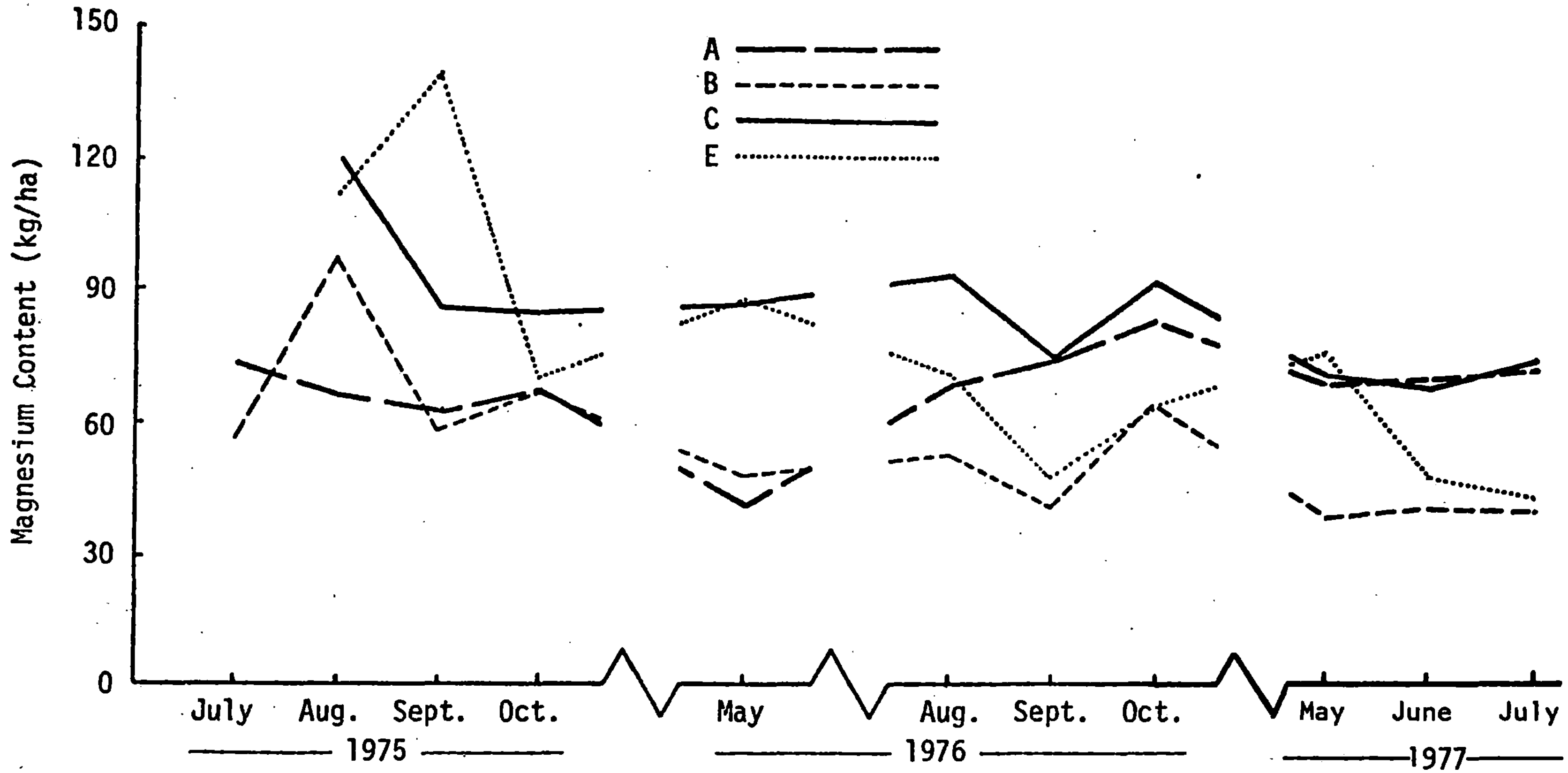



Figure 33. Adjusted Forest Floor Magnesium Contents

Magnesium concentrations of forest floor samples from the defoliated blocks, on the other hand, did not differ appreciably from those of the control blocks (Table 25 and Appendix Table B6). Hence similar concen-

Table 25. Summary of Statistical Results -- Postdefoliation Forest Floor Nutrient Concentrations

| Comparison | Ca | Mg | K | P | N |
|---|---|---|---|---|---|
| A vs B | 0[1] | 0 | ******[2] | ** | 0 |
| C vs E | 0 | 0 | ****** | ** | * |

[1]A "0" indicates no significant differences at the 5 percent level.

[2]The number of asterisks refers to the number of months following defoliation in which a statistical significance existed at the 5 percent level.

trations of magnesium were found both in the older forest floor materials and in recently defoliated needles. It thus appears that this element, like calcium, is relatively immobile with respect to short-term nutrient turnovers following defoliation.

A marked decrease in forest floor magnesium concentrations was found for each block at the start of each growing season (Appendix Table B6). This is inconsistent with the notion of relative immobility for forest floor magnesium, and suggests some over-winter leaching of the element. The effect, if real, makes the element something of an anomaly with respect to trends at the experimental site. Due to sample-to-sample variability, such over-winter changes were never statistically significant. Some of the apparent trends with time may be due to natural variations in nutrient concentrations from year to year at the site, for the summer of 1976 was considerably wetter than that of 1975, and the winter of 1976-1977 was a relatively dry one.

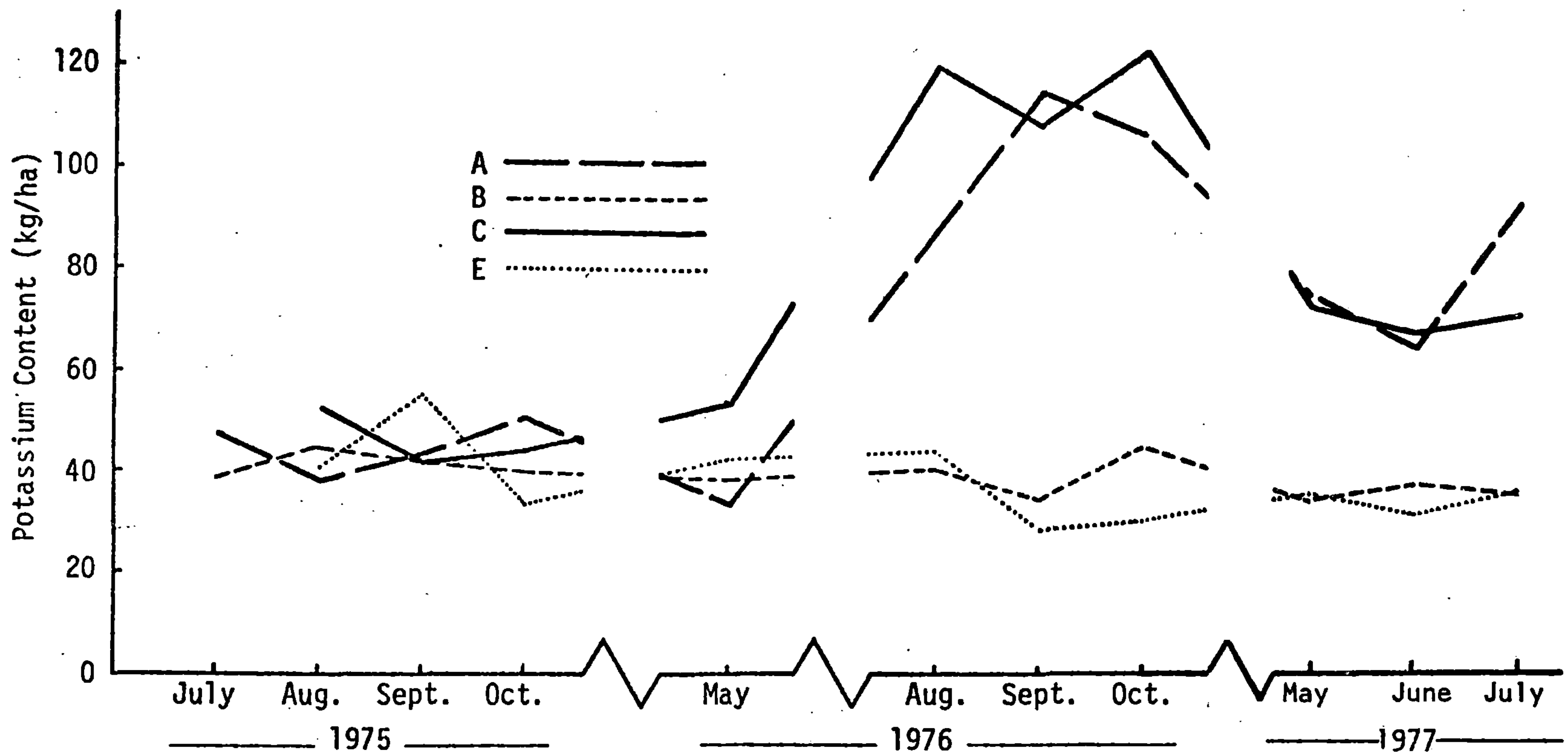



Figure 34. Adjusted Forest Floor Potassium Contents

## Potassium

Potassium contents of the forest floor samples showed drastic and significant increases following defoliation (Figure 34 and Appendix Table B7). Mean total potassium contents preceding and following defoliation for the treated blocks were 46 and 97 kg/ha, respectively. Corresponding values for the untreated blocks actually decreased slightly over the same time interval, from 42 to 38 kg/ha. Statistically significant differences in forest floor potassium concentrations were also in evidence for the paired sets of plots following defoliation (Table 25). Potassium appears to have already been leached from the older forest floor materials prior to the defoliation period. Other nutrients exhibited less drastic contrast than potassium immediately following defoliation because they tend to leach more slowly (Gosz, et.al., 1975). Assuming that the treatment blocks would have behaved similarly to the control blocks if defoliation had not occurred, the defoliation treatment added approximately 60 kg/ha of potassium to the forest floor. This increase in potassium content of the forest floor was due both to an increase in forest floor biomass and also to the fact that fresh needles have a generally higher potassium concentration than do leached forest floor materials.

Tables 24 and 25 summarize the statistical verification of increased forest floor potassium levels for the defoliated blocks during the post-defoliation period. More complete data are given in Appendix Tables B7 and B8. It was surprizing that there were no significant changes in potassium concentrations from August to October of 1976 for the defoliated blocks, in light of the continual litterfall during this period. This may reflect some leaching of potassium from freshly-fallen needles during the several summer storms of this period. That appreciable

potassium appears to have leached from the needles during the 1976-1977 over winter period is also apparent from Figure 34 and from Appendix Tables B7 and B8.

## Phosphorus

Forest floor phosphorus contents also tended to increase after defoliation, as shown in Figure 35 and in summary tables 24 and 25. Mean total phosphorus contents preceding and following defoliation for the treated blocks were 36 and 59 kg/ha, respectively. Corresponding values for the untreated blocks remained essentially unchanged over this same time interval, going from 36 to 37 kg/ha. Therefore, defoliation resulted in addition of approximately 22 kg of phosphorus per hectare to the treated blocks. Although there was a slight suggestion in Figure 35 and in Appendix Tables B9 and B10 that phosphorus might have begun to leach from the freshly-deposited needles during the 1976-1977 over winter period, such trends were considerably less pronounced than for forest floor potassium.

## Total Nitrogen

Total nitrogen contents and concentrations of the forest floor samples followed the same general trends as did phosphorus (Figure 36 and summary tables 24 and 25), including a substantial increase in forest floor total nitrogen content following defoliation. Differences were less often statistically significant, however. Mean total nitrogen contents preceding and following defoliation for the treated blocks were 371 and 535 kg/ha, respectively. Corresponding values for the untreated blocks remained virtually unchanged over the same time interval, going from 349 to 350 kg/ha. Greater variability seemed to exist in the total nitrogen values from sampling period to sampling period than was true for the other elements monitored. Judging from the concen-

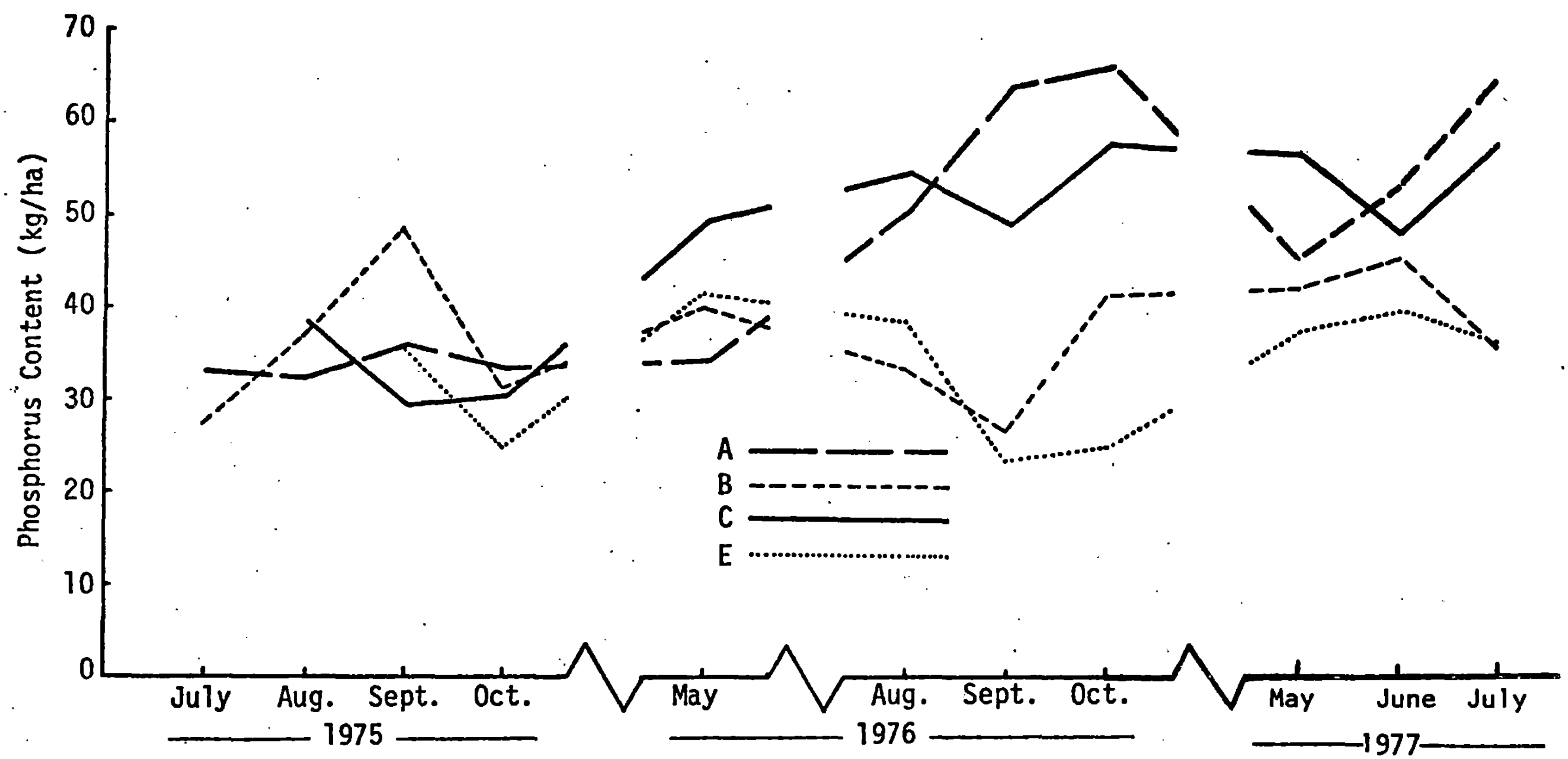



Figure 35. Adjusted Forest Floor Phosphorus Contents

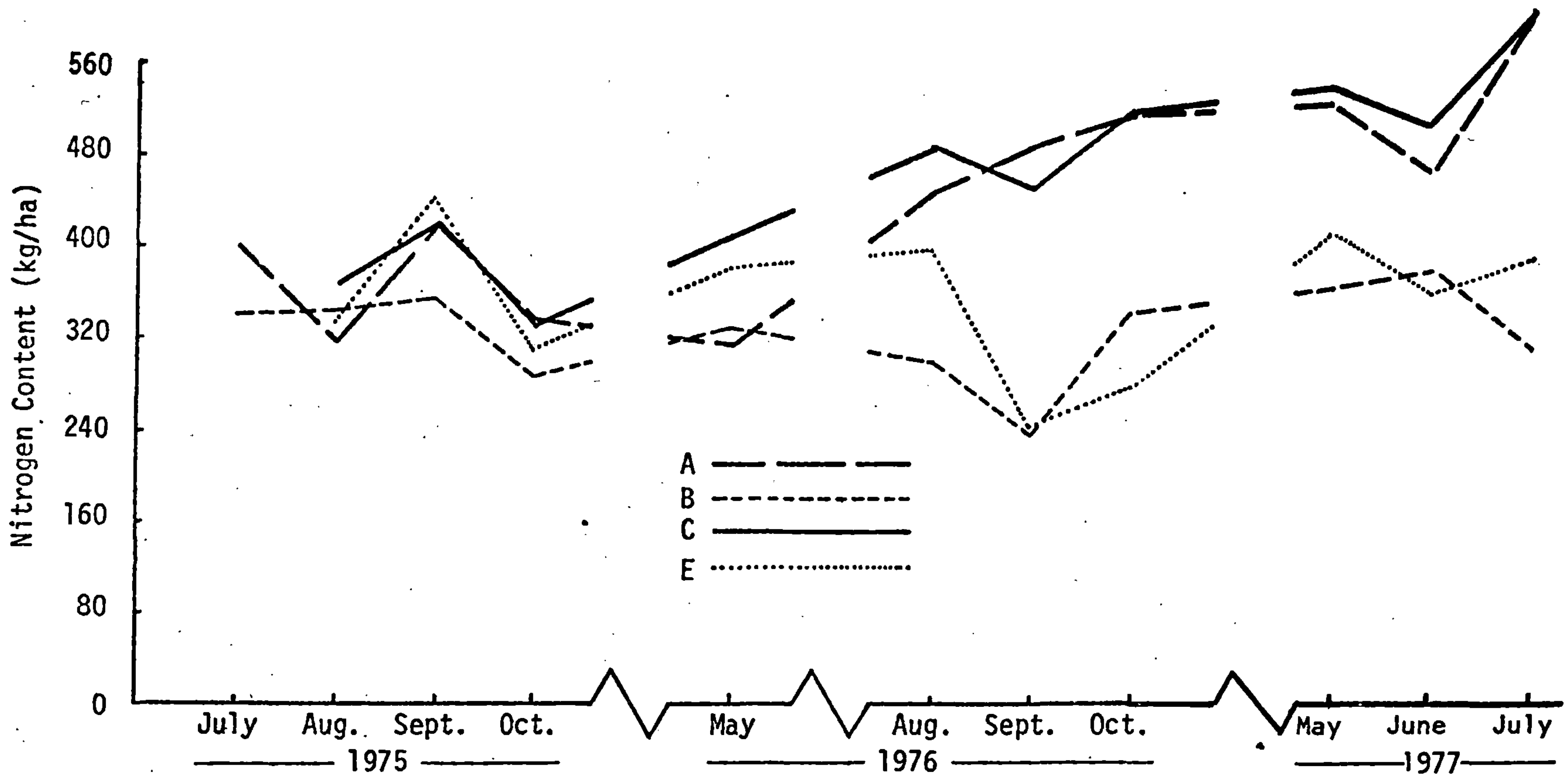



Figure 36. Adjusted Forest Floor Nitrogen Contents

tration data following defoliation (Appendix Table B12), there did not appear to be substantial differences between the nitrogen concentrations of older forest floor materials and those of the recently-deposited needles. This is consistent with the high carbon:nitrogen ratios of typical forest floor materials, and hence with their natural tendency to retain nitrogen during organic material decomposition. There were no readily-apparent trends in forest-floor nitrogen concentrations with time either prior to or following defoliation.

## Sample Variability

The extensive variation in nutrient levels of forest floor materials at this experimental site arose from two sources: (1) variations in actual nutrient concentrations, and (2) variations in the weight of forest floor samples from point to point on the landscape. These two factors combine to produce considerable variability when expressing total nutrient contents on an area basis (kg/ha). It is important to emphasize here that the site selected for this study was chosen because of its uniformity in terms both of topography and vegetation. In addition to being exceptionally level, it also had little obvious down vegetation. Therefore, it is probably considerably less variable than most forested sites of the intermountain region.

The random sampling technique used for this study, though permitting slight adjustment of actual sampling site placement to avoid obvious standing and down trees, still resulted in sampling of some decomposing woody materials buried beneath the "normal" forest floor surface. The amounts of such material could greatly influence block nutrient averages, for its large weight introduced large amounts of forest floor nutrient content variability.

The problem of forest floor sample contamination by intermixing with

immediately-underlying mineral matter is another problem which should not be overlooked. Average mineral contents of forest floor samples on the various sampling dates of this study are shown in Table 26.

Table 26. Average Mineral Contents of the Forest Floor Samples (%)

| | 1975 | | | | 1976 | | | | 1977 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Block | July | Aug. | Sept. | Oct. | May | Aug. | Sept. | Oct. | May | June | July | Oct. |
| A | 21.5 | 30.0 | 28.4 | 20.2 | 23.0 | 13.2 | 18.2 | 25.5 | 23.6 | 18.5 | 23.9 | |
| B | 19.7 | 32.3 | 27.4 | 27.4 | 26.3 | 21.6 | 22.8 | 39.2 | 32.6 | 24.9 | 36.9 | |
| C | .... | 34.5 | 24.8 | 31.3 | 31.8 | 18.3 | 15.8 | 21.2 | 20.6 | 16.6 | 22.5 | |
| E | .... | 26.8 | 29.2 | 24.4 | 27.7 | 17.6 | 18.0 | 25.2 | 22.7 | 27.8 | 27.2 | |

The data suggest that significant amounts of forest floor sample weights were derived from mineral contamination. One problem arose from difficulty in distinguishing between well-decomposed organic materials in the forest floor layer and the upper surface of the underlying mineral soil. Another arose from mixing of forest floor materials with underlying mineral soil by fauna inhabitating the forested site. On a number of occasions, we noted the presence of earthworms in the soil being sampled. Such fauna could account for a significant amount of mixing between mineral soil and forest floor materials. Also, since the boundary between mineral soil and forest floor was generally not smooth, it was easy to include a small amount of underlying mineral soil in the forest floor material. A small volume percentage of mineral matter could easily result in forest floor mineral contents as high as those indicated in Table 26. As the average thickness of forest floor at sites not containing decomposing logs was on the order of 3 to 5 cm, the amount of soil required to obtain the results of Table 26 would correspond to sampling only the surface 1 to 2 mm of mineral soil. This type of problem, coupled with potential mixing of mineral soil and forest floor by fauna in the ecosystem, makes it imperative that samples

of organic material in a forest floor be corrected for mineral matter contamination before site-to-site or time-to-time results are compared.

Correction for mineral contents of the samples collected in this study was based on the weight of sample remaining following dry combustion (at $500^{\circ}$ C for 5 hours). Preliminary studies indicated that the weight remaining following dry combustion of tree core samples (where no mineral contamination should occur) averaged less than 0.5 percent of the original sample weight. From this it was concluded that the weight of ash remaining from combustion of pure organic material is negligible compared to the actual forest floor ash weights obtained, so any weight remaining following dry combustion was assumed to be from mineral soil contamination. This is a slight over-correction for the more nutrient-rich materials of typical forest floors, but it is a reasonable first approximation to the problem. The correction for mineral matter was introduced into the calculations by decreasing the weight of sample assumed present for the dry combustion procedure.

## Soil Nutrient Distributions

The effects of Douglas-fir tussock moth defoliation on the underlying mineral soil should appear later than effects on the forest floor. Microclimate and forest floor nutrient content changes should occur first, followed by changes in microbial activity, and eventually by changes in soil nutrient levels. The latter would depend both on relative nutrient leaching patterns, and on the relative amounts of nutrients associated with defoliated biomass.

Defoliation caused little if any immediate change in surface soil moisture (0-30 cm), but the effects of overwinter soil moisture accumulations

and summer depletion patterns were readily evident (Figures 37-40, Appendix Table C1, and Table 28). The same general trends of moisture content with time were followed for all four soil depths (0-3 cm, 3-7.5 cm, 7.5-15 cm, and 15-30 cm) and for all four sample blocks. However, both the trends and the differences between treated and control blocks were accentuated by defoliation. These differences are not suprising since soil moisture depletion begins earlier and is depleted further in the surface layers than at lower depths as shown in Figure 37. Many of the differences in soil water content between treatment and control blocks were statistically significant, although these differences had also existed to a lesser extent before defoliation, because of pre-existing block characteristics.
The differences reflected consistent patterns of decreased water usage following defoliation, because of drastically-reduced amounts of transpiring plant leaf surface. Differences were greatest in mid-season,

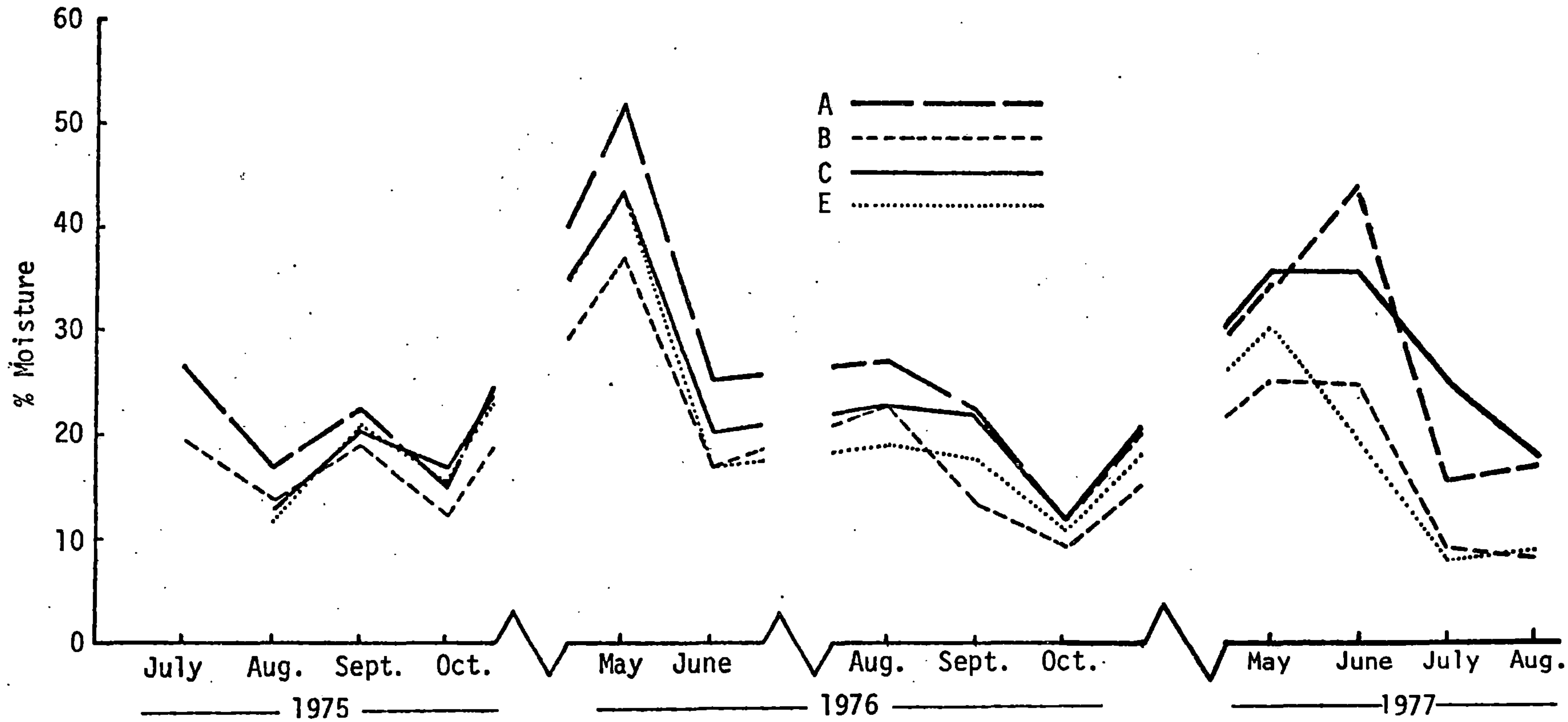



Figure 37. Soil Moisture, 0-3 cm Depth

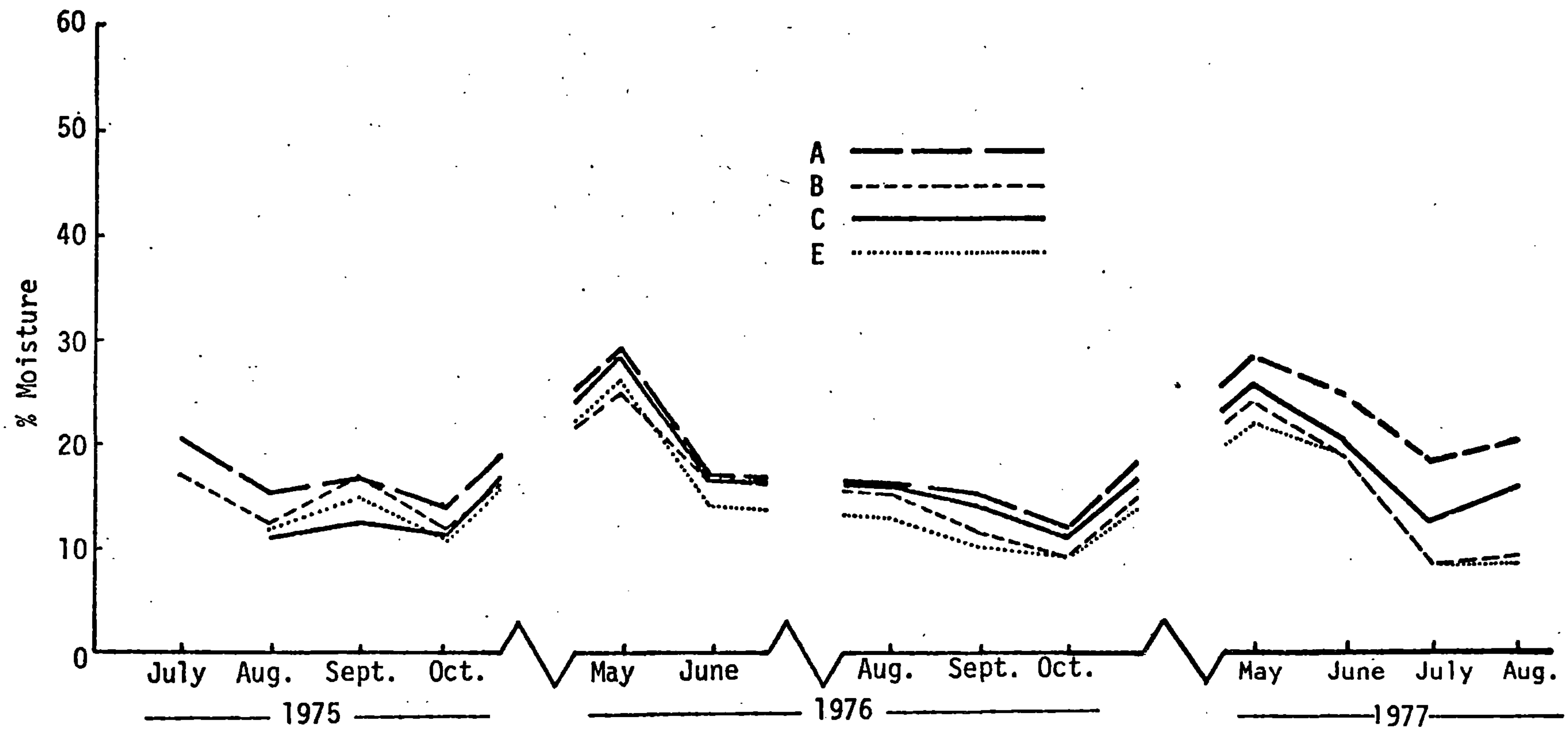



Figure 38. Soil Moisture, 3-7.5 cm Depth

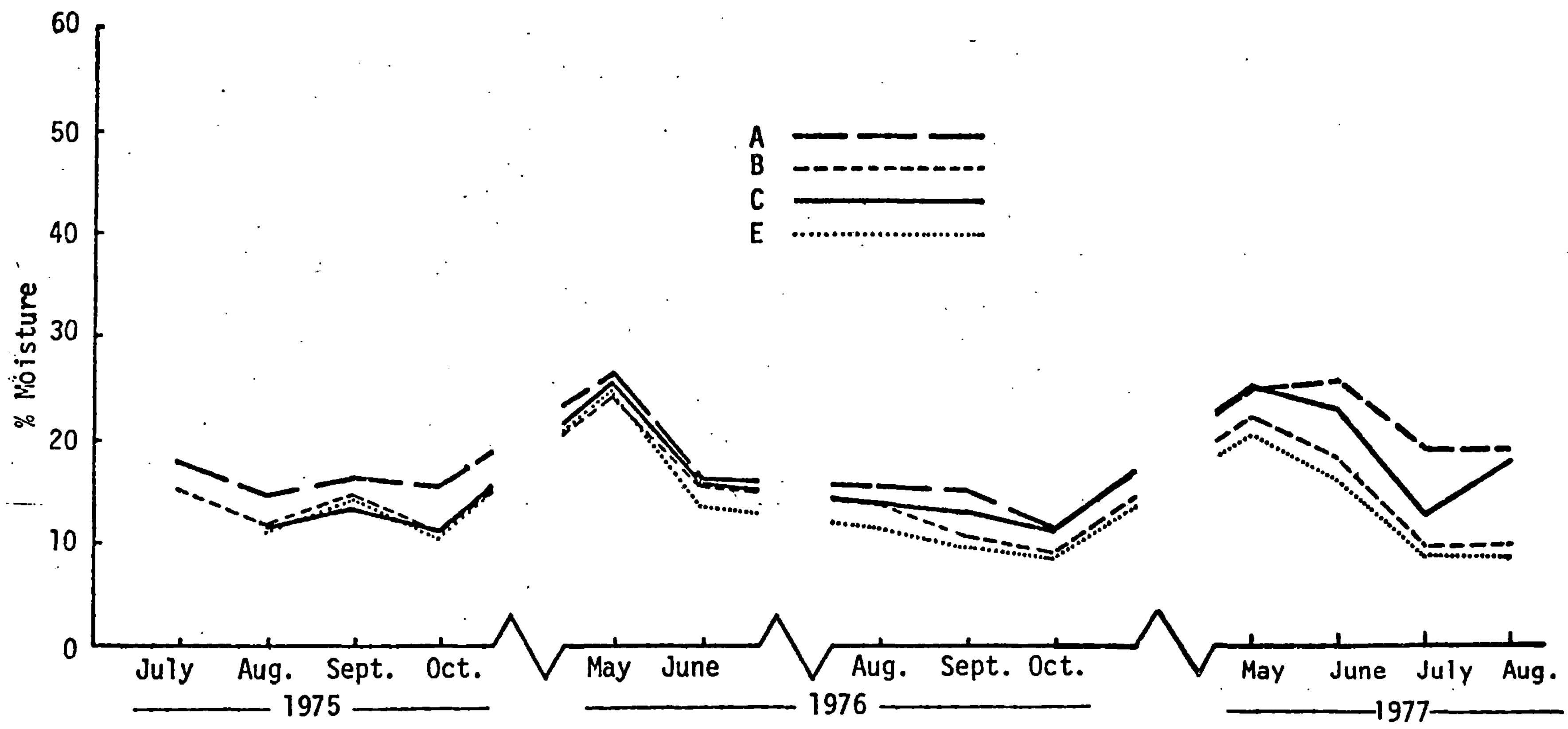



Figure 39. Soil Moisture, 7.5-15 cm Depth

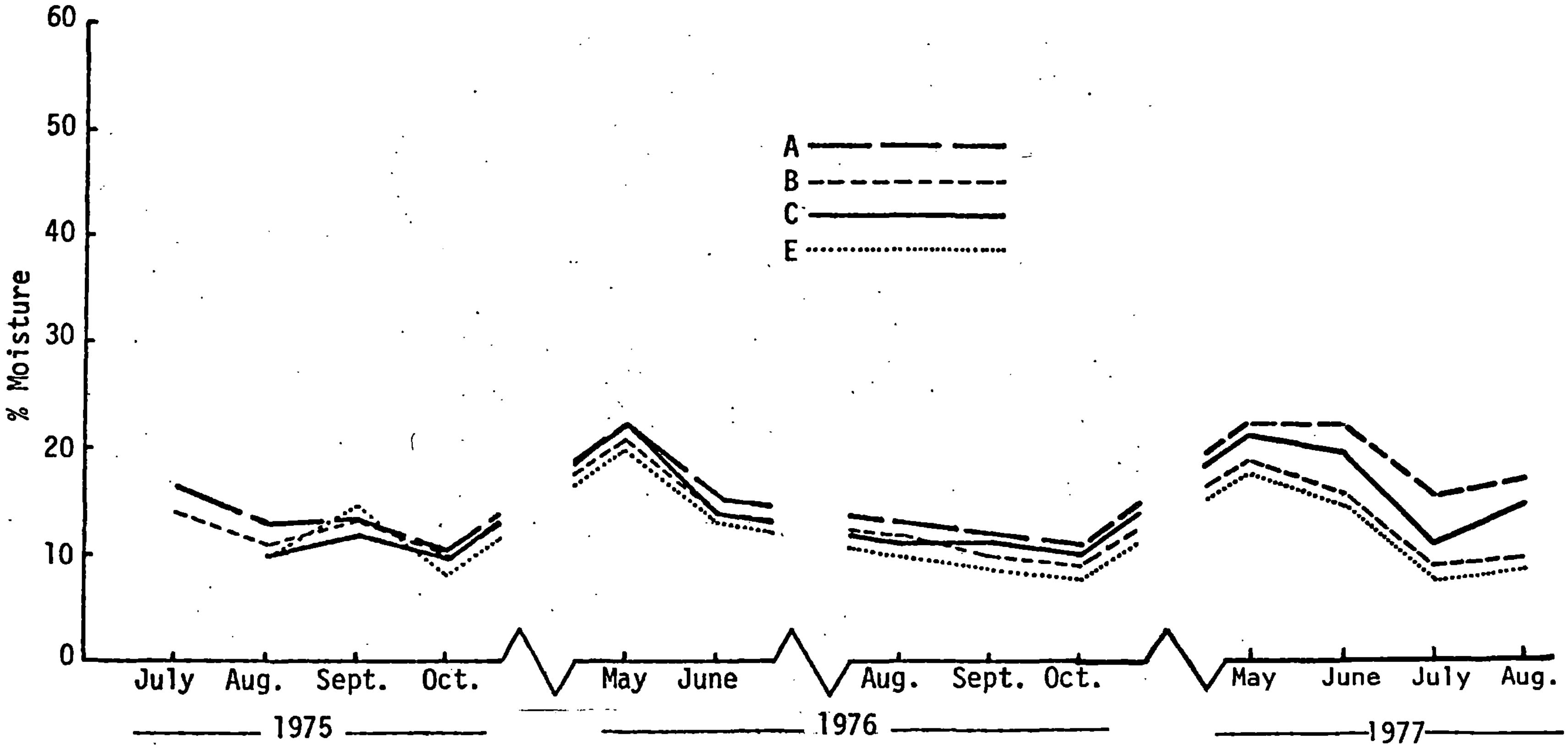



Figure 40. Soil Moisture, 15-30 cm Depth

Table 28. Average Soil Characteristics Before and After the 1976 Defoliation Period

| Depth (cm) | Block | $H_2O$(%)[1] | | $H_2O$(%)[2] | | pH[3] | | Oxidizable Material[4] (%) | | ppm Ca[3] | | ppm Mg[3] | | ppm K[3] | | ppm P[3] | | Total N[3] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After |
| | A | 20.5 | 20.8 | 34.9 | 32.6 | 5.7 | 5.9 | 5.1 | 7.4 | 2750 | 2751 | 234 | 241 | 326 | 380 | 20.8 | 21.5 | 1610 | 1455 |
| | B | 16.2 | 13.5 | 24.7 | 19.2 | 5.7 | 5.9 | 5.1 | 7.0 | 2250 | 2486 | 173 | 190 | 305 | 334 | 21.0 | 21.1 | 1255 | 1599 |
| 0-3 | C | 16.9 | 20.8 | 32.2 | 31.2 | 5.6 | 5.8 | 5.8 | 7.3 | 2280 | 2481 | 288 | 287 | 223 | 267 | 13.3 | 17.2 | 1403 | 1680 |
| | E | 16.0 | 15.0 | 30.2 | 20.7 | 5.6 | 5.7 | 4.9 | 6.7 | 2300 | 2450 | 365 | 356 | 186 | 201 | 14.6 | 15.4 | 1070 | 1294 |
| | A | 16.6 | 16.7 | 22.2 | 24.1 | 5.8 | 5.9 | 3.0 | 3.2 | 1990 | 2050 | 216 | 213 | 296 | 323 | 15.6 | 15.0 | 790 | 746 |
| | B | 14.5 | 11.8 | 19.4 | 17.5 | 5.7 | 5.8 | 2.9 | 3.3 | 1590 | 1670 | 158 | 167 | 279 | 291 | 17.9 | 17.2 | 750 | 785 |
| 3-7.5 | C | 11.6 | 15.5 | 22.4 | 21.1 | 5.6 | 5.8 | 3.5 | 3.6 | 1640 | 1807 | 251 | 251 | 182 | 199 | 9.4 | 11.7 | 750 | 892 |
| | E | 12.4 | 10.9 | 20.1 | 17.7 | 5.7 | 5.8 | 2.7 | 3.0 | 1790 | 1859 | 319 | 309 | 154 | 161 | 9.6 | 11.4 | 660 | 660 |
| | A | 15.8 | 15.7 | 20.0 | 23.4 | 5.8 | 5.9 | 2.0 | 2.1 | 1790 | 1825 | 215 | 213 | 276 | 308 | 13.9 | 13.3 | 580 | 574 |
| | B | 13.1 | 11.9 | 18.2 | 16.3 | 5.8 | 5.8 | 2.2 | 2.3 | 1440 | 1481 | 161 | 163 | 268 | 283 | 16.8 | 16.3 | 570 | 626 |
| 7.5-15 | C | 11.7 | 14.8 | 20.6 | 20.1 | 5.7 | 5.7 | 2.4 | 2.6 | 1470 | 1533 | 240 | 237 | 167 | 176 | 8.5 | 10.1 | 670 | 730 |
| | E | 11.8 | 9.6 | 19.1 | 14.9 | 5.8 | 5.8 | 2.1 | 2.1 | 1650 | 1663 | 302 | 290 | 143 | 146 | 9.7 | 10.1 | 550 | 499 |
| | A | 13.4 | 13.9 | 18.2 | 19.8 | 5.7 | 5.8 | 1.2 | 1.3 | 1670 | 1778 | 210 | 213 | 269 | 296 | 14.0 | 13.6 | 380 | 409 |
| | B | 12.1 | 10.2 | 16.4 | 14.6 | 5.7 | 5.8 | 1.2 | 1.3 | 1420 | 1425 | 169 | 163 | 256 | 276 | 17.0 | 17.1 | 370 | 435 |
| 15-30 | C | 10.6 | 12.7 | 18.3 | 17.1 | 5.6 | 5.7 | 1.5 | 1.7 | 1260 | 1359 | 224 | 229 | 158 | 168 | 7.0 | 8.8 | 440 | 498 |
| | E | 10.8 | 8.9 | 16.6 | 13.6 | 5.7 | 5.7 | 1.3 | 1.4 | 1480 | 1490 | 283 | 278 | 133 | 138 | 7.7 | 8.2 | 380 | 391 |

[1] Averages are for August, September, and October of each year.

[2] Averages are for May, June, and July of each year.

[3] Averages are for all time periods before and after defoliation.

[4] Averages are for September and October of 1975 (before), August and September of 1976 (after), and May, June, and July of 1976 (after).

Table 29. Summary of Statistical Results--Soil Concentrations

| Depth (cm) | Comparison | Ca | Mg | K | P | Total N | Mineral N | Moisture | pH |
|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A vs B | 0[1] | ***[2] | * | 0 | * | 0 | ****** | * |
| | C vs E | 0 | **** | *** | ** | ** | *** | **** | 0 |
| 3-7.5 | A vs B | ***** | **** | * | 0 | * | --- | ****** | * |
| | C vs E | ** | ***** | 0 | 0 | *** | --- | ****** | 0 |
| 7.5-15 | A vs B | ****** | ****** | * | *** | 0 | --- | ****** | 0 |
| | C vs E | * | ****** | 0 | 0 | **** | --- | ******* | 0 |
| 15-30 | A vs B | ***** | ***** | * | **** | * | --- | ******* | * |
| | C vs E | 0 | ***** | * | 0 | *** | --- | ******* | 0 |

[1]A "0" indicates no significant differences at the 5 percent level.

[2]The number of asterisks refers to the number of months following defoliation in which a statistical significance existed at the 5 percent level.

for the soil profile was more completely charged with water in early season, and water shortages reduced plant water usage on the control blocks by late season. Differences also tended to be greatest for the more shallow soil depths, where the greater proportion of normal plant root activity is located.

## General Soil Nutrient Trends

Soil calcium, magnesium, potassium, and phosphorus concentrations generally followed the same trends during the first two years of study, decreasing from July to August or September, and then increasing once more through October and apparently peaking during the winter or early spring (Appendix Tables C2 to C5). Peak sample nutrient concentrations probably occurred in May only because samples were not collected earlier in the season, due to snow cover and to general inaccessibility of the site. Such a cycle of soil nutrient concentration versus time can be

explained by anticipated trends both of nutrient uptake by plants and of microbial breakdown of forest floor materials. In the fall and winter months, once soil moisture begins to accumulate from the fall rains, microbes decompose surface and soil organic matter and release nutrients that accumulate in the soil horizons. Since on-site vegetation, and especially the deciduous vine maple understory, has decreased nutrient requirements during the late fall and winter months, it does not remove as many nutrients as the microbes release during this period. This results in an accumulation of nutrients in the soil. During the late spring and early summer months, the vegetation actively absorbs both nutrients and water. The decreasing moisture contents of the soil and forest floor eventually result in slowed microbial decomposition of organic material. This, coupled with the uptake by vegetation and reduced leaching of nutrients out of the forest floor, causes decreased soil nutrient concentrations until the fall accumulation period is entered once more.

Such seasonal trends of nutrient concentrations appeared to be most pronounced for the 0-3 and 3-7.5 cm soil depths, and were less apparent with increasing depth in the profile. This suggests that soil nutrient concentration variability should also be greater near the soil surface than at greater depths in the profile.

## Soil Nutrient Trends Following Defoliation

The general seasonal trends were less apparent during 1977, the first full year following defoliation (Appendix Tables C2 to C5). Early-season soil calcium levels exceeded values for the October 1976 sampling date only for block C, and the normal trend of decreasing soil calcium values during the growing season were only weakly evident for blocks C and E. A <u>reversed</u> trend actually existed for blocks A and B during

the 1977 growing season, with soil calcium levels increasing as the season progressed. This could be explained for the defoliated plot by microbial release of nutrients without concurrent plant nutrient uptake (due to decreased water uptake and hence decreased nutrient movement to the vicinity of the plant roots). The similar trend for control block B lessens the liklihood that this is an adequate explanation, however. Extractable soil calcium levels were higher for defoliated block A than for its control block B, but this could be viewed as simply an extension of predefoliation trends. Hence, the statistical differences with respect to soil calcium in table 29 reflect plot to plot trends rather than treatment-induced differences. No substantial changes were apparent for blocks C and E, in either the Appendix tables or in summary tables 28 and 29.

In addition to the Appendix and summary tables, trends in soil magnesium values before and after defoliation can be seen through figures 41 to 44. Magnesium concentrations in treated and control blocks were significantly different throughout the entire period of the study, but no effects of defoliation were evident for either block A or block C. The fact that no significant changes in soil nutrient concentrations occurred in 1976 might have been expected, as the defoliation treatment was only completed at the end of July in 1976, which left only two months of elapsed time for changes to occur. This period also coincided with the period when annual soil nutrient concentrations were decreasing and when the soil was driest, so that microbial activity should have been decreased. The late summer period is the time when changes in the nutrient status of the soil are least likely to occur. As the time interval was too brief and the soil too dry for appreciable nutrient movement to the soil

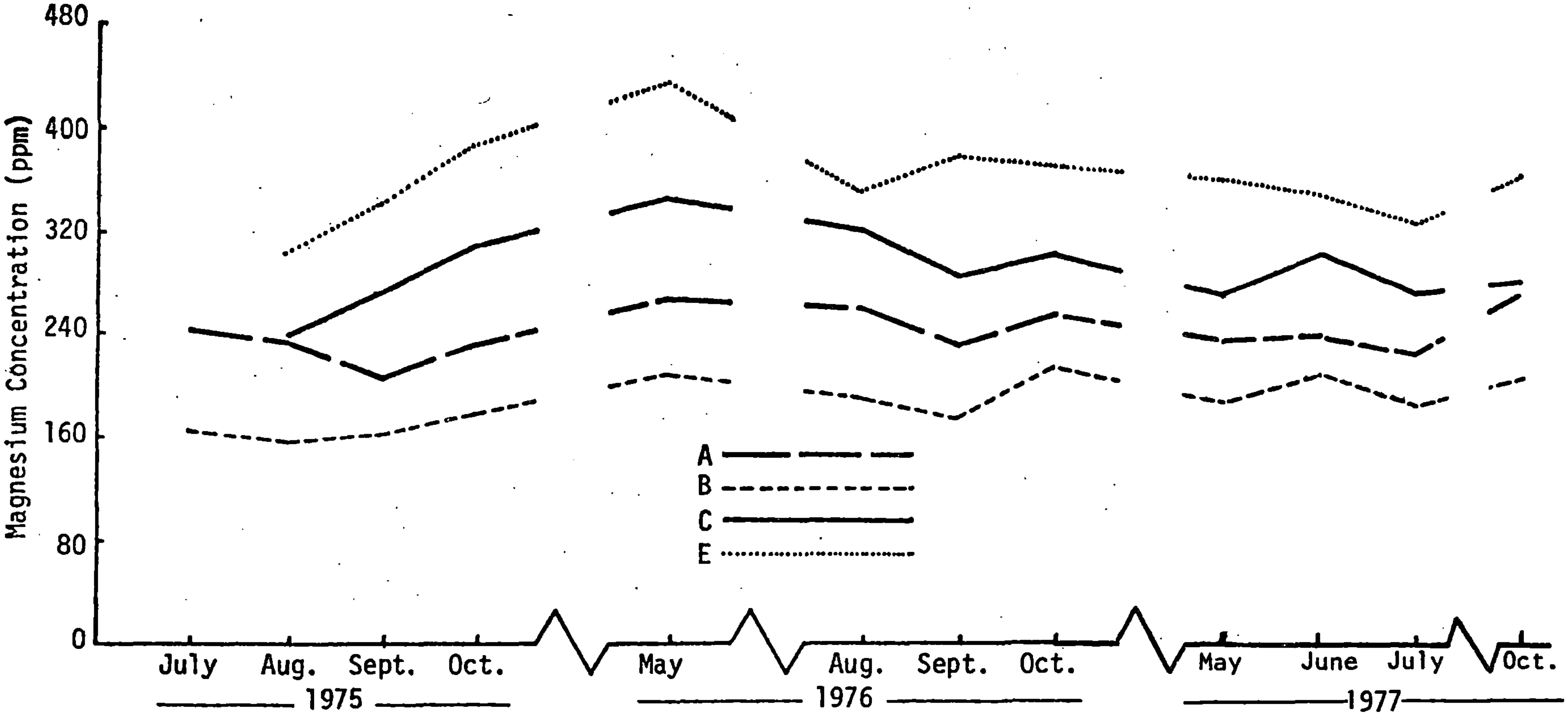



Figure 41. Extractable Soil Magnesium 0-3 cm Depth

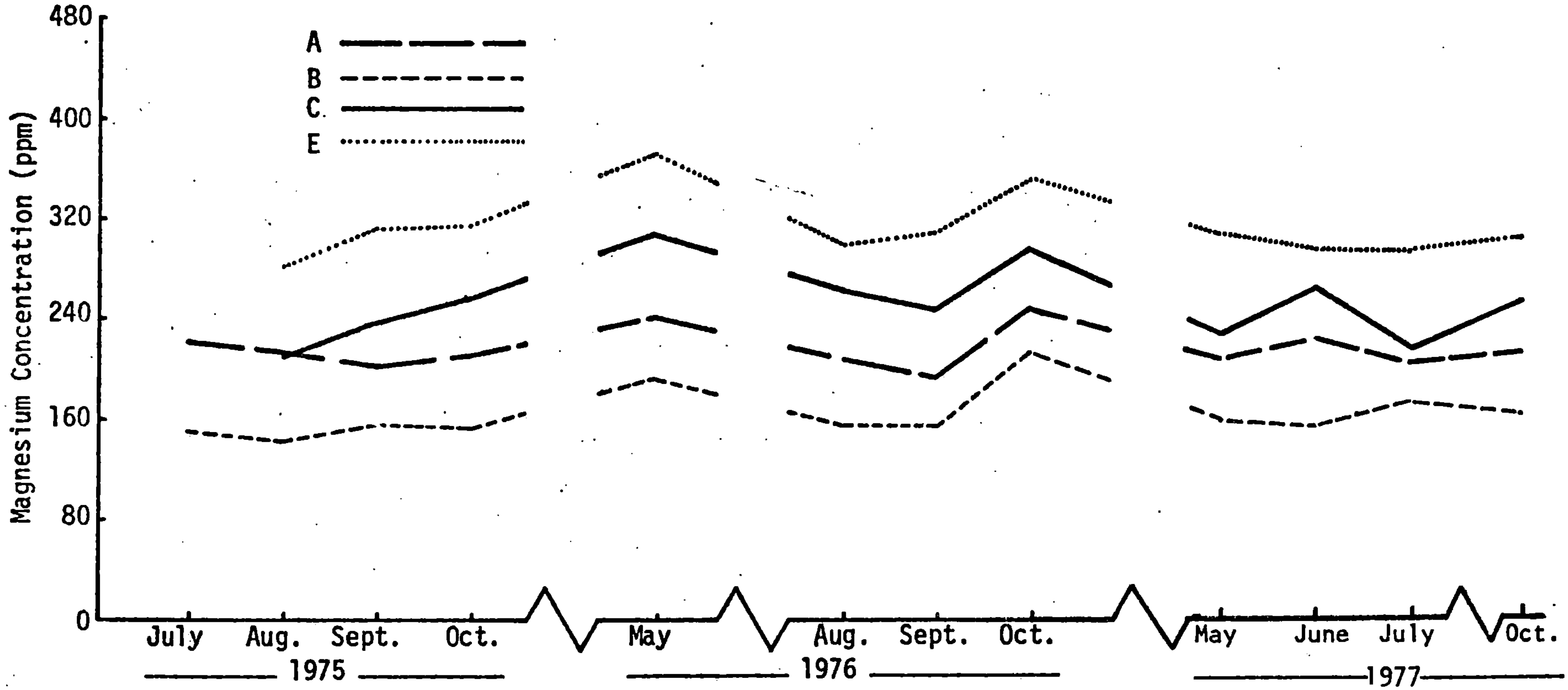



Figure 42. Extractable Soil Magnesium, 3-7.5 cm Depth

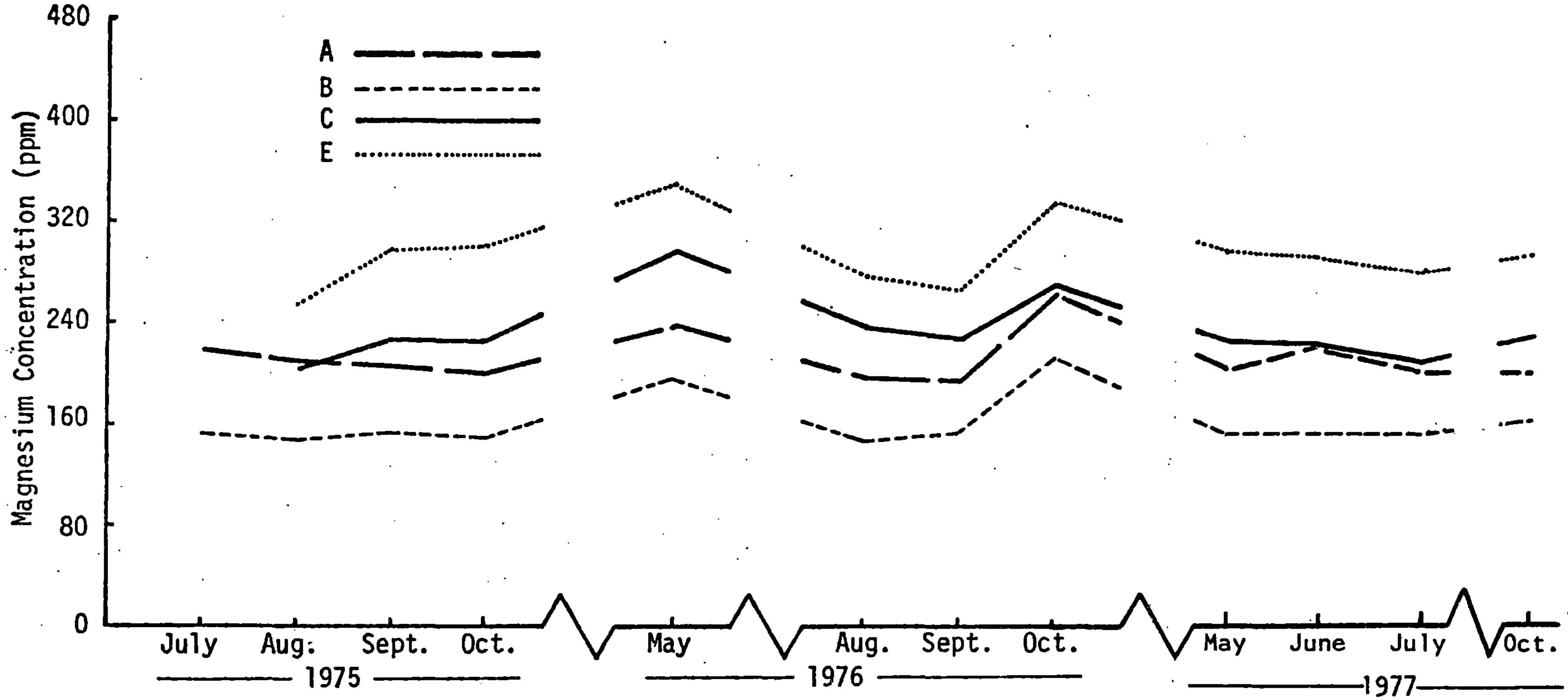



Figure 43. Extractable Soil Magnesium, 7.5-15 cm Depth

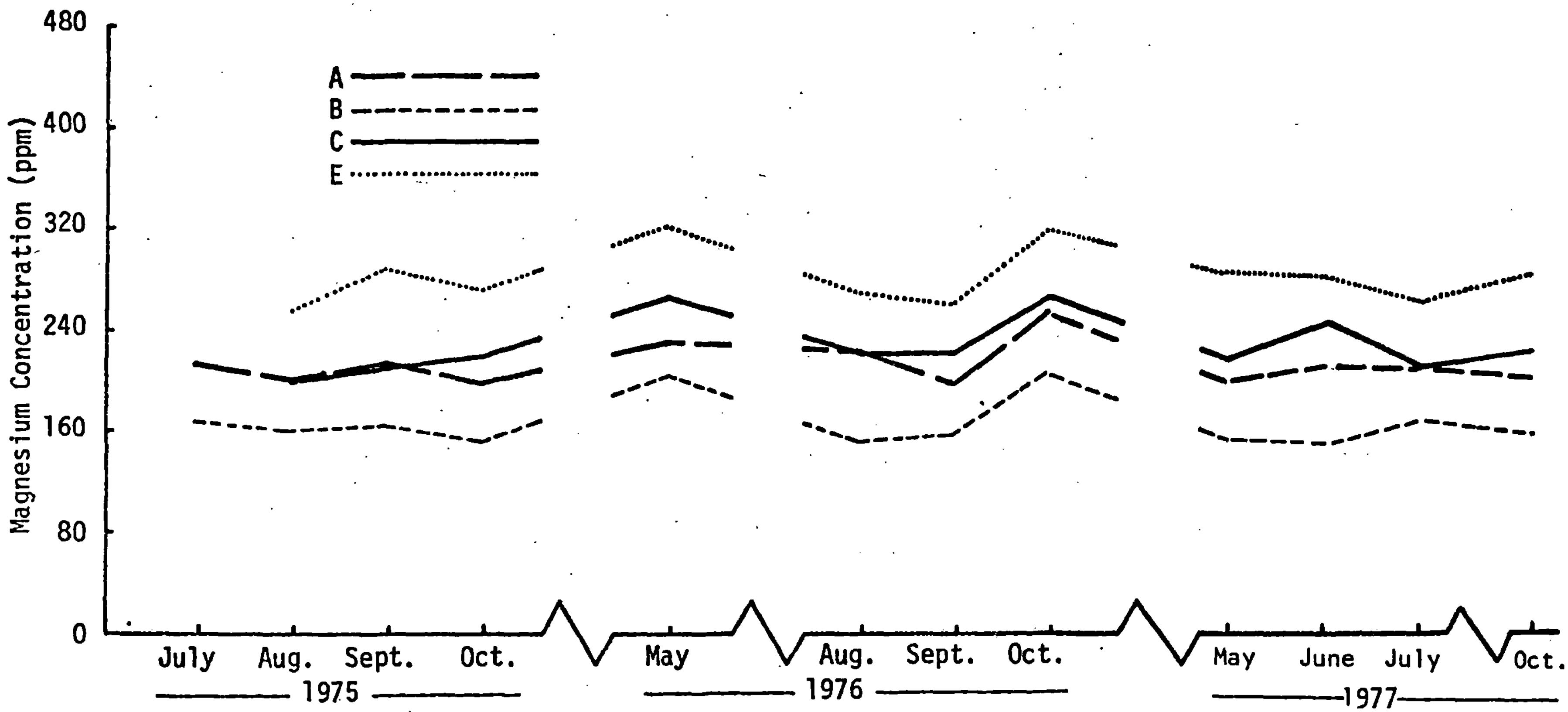



Figure 44. Extractable Soil Magnesium, 15-30 cm Depth

from the forest floor, any changes which did occur would have to arise from microbial transformations or chemical changes accompanying soil temperature and moisture content differences in a given soil depth increment itself. The fact that significant changes did not occur during the over-winter period or during the 1977 season was more meaningful, however. That extractable soil magnesium values were virtually unchanged by defoliation is evident from the four figures and from Table 28. As with calcium, the normal over-winter accumulation of nutrients was not evident in the 1977 data, nor were the normal within-season soil nutrient trends. Also as for calcium, the statistically-significant differences reported in Table 29 reflected preexisting block to block differences, rather than defoliation-induced trends.

Table 28, which has already been referred to, presents average values for each of the soil parameters monitored, with respect both to depth increment and to defoliation period. The data indicate that calcium is the dominant exchangeable cation in the soils at the site, with soil calcium concentrations, as well as those of other soil nutrients, decreasing with depth in the profile. This decrease is because forest soil nutrient concentrations decrease, in general, with increasing distance from the source of nutrient supply, the decomposing forest floor, and also because cation exchange capacity of such soils normally decreases with depth, because of decreasing organic matter content. Blocks tended in general to maintain the same relative soil nutrient concentrations both before and after defoliation and with increasing depth in the profile. This was true for all nutrients, although the relative positions were not always the same for each nutrient. For calcium, the sequence of blocks probably reflects cation exchange capacity trends from block to block, due to soil organic mat-

ter and/or textural differences.

Soil magnesium values followed the same general trend of decreased concentration with increasing depth in the profile. However, blocks C and E contained much higher concentrations of magnesium than did blocks A and B. This can possibly be explained by parent material differences between the two sets of sites. As block E is closest to the base of a nearby hill, it is possible that some material, relatively higher in magnesium-containing minerals, has been deposited on the site by soil movement downslope. The difference in magnesium concentrations between blocks A and B versus blocks C and E is statistically significant (Appendix Table C3).

Both soil potassium and soil phosphorus showed similar trends, with blocks A and B containing significantly higher concentrations of the two nutrients than blocks C and E. This may be explained by vegetation differences between the two sets of blocks. Blocks C and E support stands of larger trees and a dense understory of vine maple, whereas blocks A and B support stands of smaller trees at a higher stocking rate. The trees compete with the understory to such an extent that there is little understory vegetation on either of blocks A and B. For a pine forest in Connecticut, understory vegetation contained twice the potassium concentration, and also higher phosphorus concentrations, than did overstory trees (Scott, 1955). An understory of vine maple would concentrate most of its roots in the top 30 cm of soil. Hence, if the vine maple at our site followed the patterns reported by Scott, this could explain the lower concentrations of potassium and phosphorus in the soil of blocks C and E.

With respect to time trends, the early-season increases in soil nutrient levels were evident in May of 1977 for both potassium and phosphorus, particularly at the most shallow soil depth (Appendix Tables

C4 and C5), though subsequent within-season decreases in soil nutrient levels were not evident. The over-winter increase was particularly pronounced for the more shallow soil depths of the defoliated plots, when compared to their corresponding controls, and was generally greater for potassium than for phosphorus. Because of the apparent leaching of potassium and the likely leaching of phosphorus as well from overlying forest-floor materials, the increases may reflect nutrient movement into the soil from recently-deposited needles on the defoliated plots. If this is a proper interpretation, it is one of the first demonstrable chemical effects of defoliation on soils of the site. With the large amount of site-to-site sampling variability, the trends, though consistent, were not statistically significant (Table 29).

Soil total nitrogen concentrations were very high in the surface 3 cm of soil and then decreased by almost 50 percent in the 3-7.5 cm depth (Table 28). As would be expected, there exists a relationship between soil total nitrogen concentration and content of oxidizable material (primarily carbon). Averages of carbon to nitrogen ratios with increasing depth in the soil profile, as calculated from our data, were 26, 24, 21, and 18. This trend results from two effects: soil microbes work to decrease the ratio of carbon to nitrogen so the ratio is lower the more the material has been decomposed, and the method used to determine easily oxidizable material (a modified Walkley-Black procedure without external heating) is subject to variations with the type of organic compound present. Organic materials that are not easily oxidized will not show up in this type of organic carbon determination. Such materials also tend to decompose more slowly and to be transported more deeply into the soil profile than do more easily-oxidized materials. These combined effects result in smaller

carbon to nitrogen ratios with increasing depth in the soil profile. With the exception of block E, for which a reversed trend was evident, total nitrogen values tended to decrease during the growing season, and to increase during the over winter period. Unfortunately, with the bulk of the nitrogen in relatively non-labile forms, such a trend had not been anticipated. Seasonal trends would have been expected for the more labile fractions, such as mineral nitrogen, only. As indicated earlier, there was considerably more variation in total nitrogen levels with sampling period than for other nutrient analyses. The extent to which the apparent seasonal trends are real, and the extent to which they reflect some procedural artifact, remains unresolved at present. The trends were not in general statistically significant, except in cases where they reflected predefoliation trends (Table 29).

Soil pH was essentially constant throughout the experimental site and the experimental period (Appendix Table C7, and Table 28). There appeared to have been a slightly greater increase in the most shallow soil depths for the defoliated plots during the post-defoliation period, but the trend was not statistically significant (Table 29).

Oxidizable material showed substantial increases from 1975 to 1977, with the increases being most pronounced for soil samples from the 0 to 3 cm depth. The changes were more probably artifacts than a result of defoliation, however, for increases were approximately the same for both control blocks as for their defoliated counter parts.

## Mineral Nitrogen

Soil mineral nitrogen concentrations (Table 28, Appendix Table C9, and Figure 15) exhibited no significant trends (particularly with

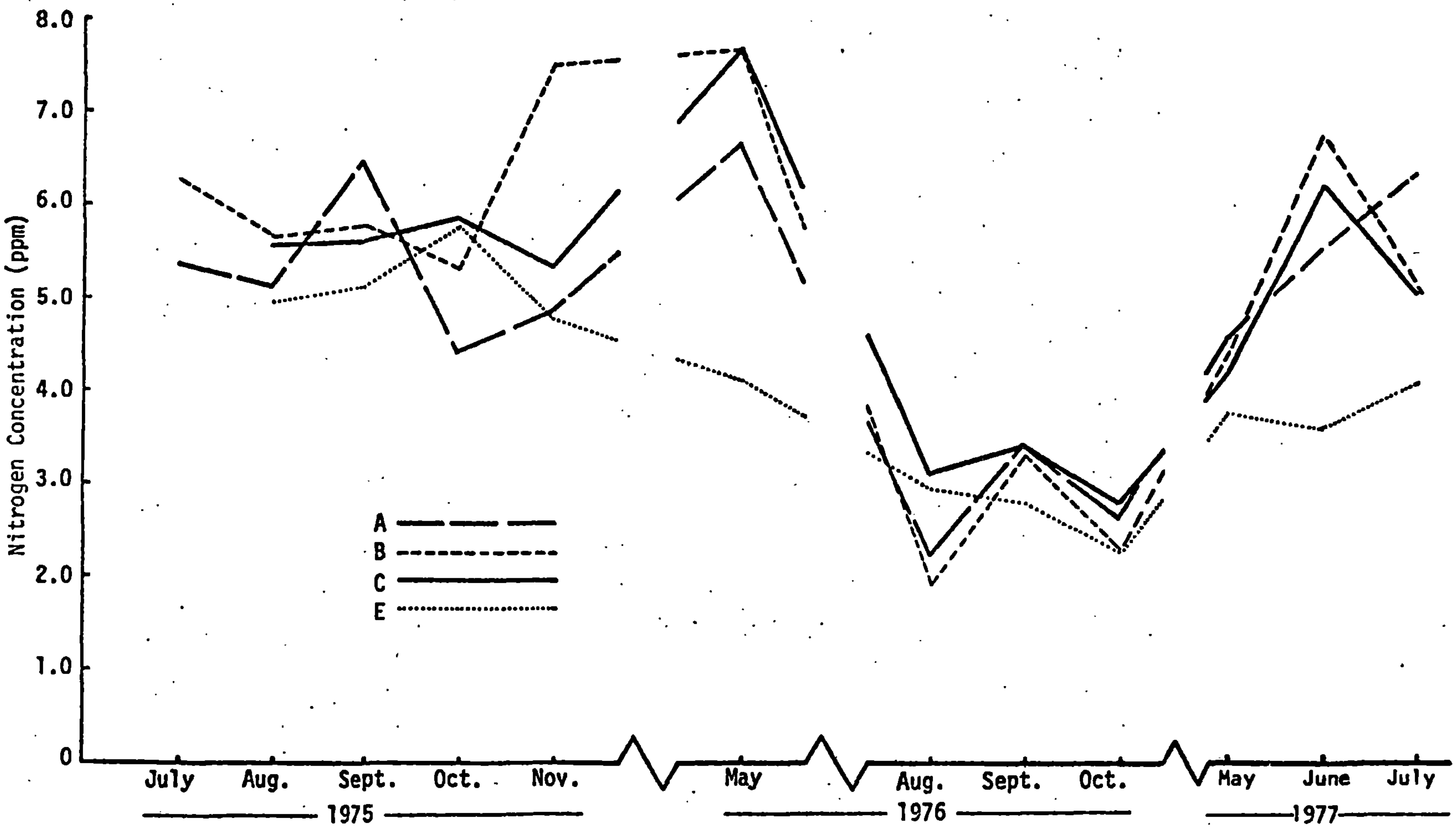



Figure 45. Soil Mineral Nitrogen

respect to the defoliation treatments), other than the fact that average concentrations for all blocks were significantly lower in 1976 than in 1975, and were somewhat higher again in 1977. The conspicuous increases in mineral nitrogen concentrations of Blocks A, B, and C in May of 1976 were probably due to poor handling of the samples. Several samples from each of these plots were dried in a convection-type oven, rather than the dorced-draft facility which was normally used. This resulted in such slow drying that some samples were still not dry after 10 hours in the oven at $60^{\circ}$ C. As a consequence, microsites could have remained within clods which were both moist and warm, and which would have provided excellent conditions for rapid nitrogen mineralization. These samples contained as much as 19 ppm mineral nitrogen, and each was as high or higher than the highest values obtained from properly treated samples. This reinforces previous conclusions that such samples be spread in a thin layer in a forced-draft oven for drying so that they will dry in only one or two hours.

The range of soil mineral nitrogen concentrations was from 2.0 ppm to 7.7 ppm. Such values are extremely low, making it hard to distinguish any significant differences resulting from defoliation. At least there was no immediate flush of soil mineral nitrogen, as had been expected if increased microbial activity followed defoliation, unless the gradually widening differences between averages for Blocks C and E reflected a small-scale version of the anticipated trend. The flush may have been prevented by substantial nitrogen immobilization due to added forest floor needle materials (Bartholomew, 1965).

Influence of Defoliation on Future Stand Productivity

Once relative changes in the abiotic fluxes (water, nutrients, energy, etc.) within a canopy have been determined for defoliated conifer stands, a method is needed to determine these effects on the future growth and/or productivity of the stands. The most obvious method would be longterm monitoring. However, the scope and time frame of this research project does not allow this flexibility.

To predict possible changes in the future productivity in the experimental blocks (stands) where we have measured changes in the abiotic fluxes brought about by defoliation, we have attempted to use the Stand Prognosis Model (Stage, 1973) being developed for the DFTM Research Program by Drs. A. Stage and R. Monserud at the Intermountain Forest and Range Experiment Station, Moscow, Idaho. This stand prognosis model is being developed to provide simulated growth of stands before and after defoliation by the Douglas-fir tussock moth.

We measured on all trees in both the control and defoliated blocks the species, diameter, percent defoliation, percent live crown, age, height, and growth in 10-year increments back to the starting date of the tree. From this information we were able to determine basal area percentile by species and make an estimate of mortality by species, all information needed for the model.

With the use of the Stand Prognosis Model, we have attempted to look at the future growth in 50-year increments for 45 years past the present, considering our defoliation treatment to occur in year 1977, under several possible stand conditions. The first stand condition tested is that of its

present condition without management over the next 50 years. Our simulated defoliation and the consequent attack by spruce budworm resulted in significant mortality, mostly on smaller diameter trees. The second condition was to consider the removal or loss in growth of this dead material as might be the case in a salvage logging operation. The third condition was to predict future growth using the mortality of condition two, but allowing a hypothetical growth rate for the remaining trees that have been affected by changes in the abiotic fluxes within the defoliated stand. We used a hypothetical growth rate based on information shown in Figure 1. Our hypothetical growth rate for the defoliated stand was determined to be 1.5 percent of the basal area from year 0 to 5, while the control was 5.5 percent. In the defoliated block the basal area growth was simulated at 26 percent for years 6-15, 19 percent for years 16-25, and 17 percent for years 26-35, while the control stand remained constant at 11 percent for each of the 10-year increments. Thus, our growth multipliers in the prognosis model for condition three were 0.95 from 1977 to 1982, 1.15 from 1983 to 1992, 1.08 from 1993 to 2002, 1.04 from 2003 to 2012, and 1.0 from 2013 to 2027.

Predicted stand volumes for the three growth conditions tested with the Stand Prognosis Model for experimental Blocks A and C are shown in Table 30. Blocks B and E were not tested since they were not defoliated. The model predicts that under normal stand growth Blocks A and C will increase 199.3 and 284.3 $m^3/ha$ (2848 and 4063 $ft^3/A$) from 1977 to 2027. We have estimated that in Block A 11 percent or 73.1 $m^3/ha$ (1045 $ft^3/A$) of the stand volume was lost to mortality because of defoliation. In Block C the mortality was 21 percent or 108.7 $m^3/ha$ (1553 $ft^3/A$). This volume could be considered available for salvage logging. In the period 1977-2027, the defoliated Blocks A and C stands (condition two) were predicted to increase by 206.4 and 291.9 $m^3/ha$ (2952 and 4171 $ft^3/A$), slightly greater volumes than were predicted for the unaffected or normal stand conditions. The mortality because of defoliation appeared to be on the smaller suppressed trees as 26.6 and 37.0 percent of the trees were lost to mortality in Blocks A and C, respectively. Thus, the volume growth in the defoliated stands appears to have been shifted to the more dominant trees much as is attempted in stand improvement thinnings. When we attempt to account for possible increases in growth due to changes in abiotic fluxes (condition three), volume increases over 50 years raised to 213.5 and 300.3 $m^3/ha$ (3051 and 4292 $ft^3/A$) for Blocks A and C, respectively.

Probably more important than changes in total volume over 50 years is the prediction that even after 11 to 21 percent of the volume is lost due to defoliation mortality, the stands appear to have greater volumes of live standing wood after 35 to 40 years than the stands that were not affected by defoliation. When changes in volume due to the possible influence of changes in the abiotic fluxes (nutrient availability, etc.) are projected, stand

volumes in the defoliated stands equal and exceed those of unaffected stands in 20 to 25 years. Thus, it appears from data projected by the model that volume growth loss by stand with volume losses due to defoliation mortality from 11 to 21 percent will be recovered rather quickly, possibly less than 25 years.

Although many factors can influence a stand's growth patterns over a 50-year period in the future including forest management activities, i.e. commercial thinning, etc., it does appear that on unmanaged stands defoliation by phytophagous insects may have some positive effects on a forest site's future productivity.

Table 30. Influence of simulated Douglas-fir tussock moth defoliation on future stand volumes as determined by the Stand Prognosis Model for experimental Blocks A and C.

| Year | (1) Normal Growth[1/] | (2) Defoliated 1977[2/] | (3) Δ Volume (2)-(1) | (4) Defoliated 1977[3/] | (5) Δ Volume (4)-(1) | (6) Δ Volume (5)-(3) |
|---|---|---|---|---|---|---|
| | $m^3/ha$ | | | | | |
| Block A | | | | | | |
| 1977 | 649.2 | 649.2 | | 649.2 | | |
| mortality (1977)[4/] | | 73.1 | | 73.1 | | |
| 1982 | 683.1 | 620.0 | -63.1 | 617.1 | -66.0 | 2.9 |
| 1987 | 712.2 | 663.8 | -48.4 | 670.5 | -41.8 | 6.6 |
| 1992 | 737.5 | 702.4 | -35.1 | 716.8 | -20.7 | 14.4 |
| 1997 | 761.2 | 737.2 | -23.9 | 754.1 | -7.1 | 16.9 |
| 2002 | 781.4 | 766.5 | -14.8 | 784.7 | 3.4 | 18.2 |
| 2007 | 794.7 | 786.6 | -8.1 | 803.3 | 8.6 | 16.7 |
| 2012 | 810.8 | 809.4 | -1.3 | 824.8 | 14.1 | 15.4 |
| 2017 | 823.6 | 826.6 | 3.0 | 838.6 | 15.0 | 12.0 |
| 2022 | 838.3 | 843.4 | 5.0 | 852.7 | 14.3 | 9.3 |
| 2027 | 848.5 | 855.6 | 7.3 | 862.7 | 14.2 | 6.9 |

Table 30. (Continued)

| Year | (1) Normal Growth 1/ | (2) Defoliated 1977 2/ | (3) Δ Volume (2)-(1) | (4) Defoliated 1977 3/ | (5) Δ Volume (4)-(1) | (6) Δ Volume (5)-(3) |
|---|---|---|---|---|---|---|
| | ------- | ------- | ------- $m^3$/ha | ------- | ------- | ------- |
| Block C | | | | | | |
| 1977 | 518.2 | 518.2 | | 518.2 | | |
| mortality (1977) 4/ | | 108.7 | | 108.7 | | |
| 1982 | 566.2 | 465.3 | -100.9 | 473.2 | -93.0 | 7.9 |
| 1987 | 604.4 | 521.2 | -83.2 | 535.9 | -66.6 | 16.6 |
| 1992 | 639.3 | 574.5 | -64.8 | 598.4 | -40.9 | 23.9 |
| 1997 | 669.7 | 623.1 | -46.6 | 648.2 | -21.5 | 25.1 |
| 2002 | 696.8 | 665.4 | -31.5 | 690.8 | -6.0 | 25.5 |
| 2007 | 723.1 | 704.8 | -18.3 | 727.5 | 4.4 | 22.7 |
| 2012 | 744.5 | 735.9 | -8.6 | 756.1 | 11.5 | 20.2 |
| 2017 | 765.1 | 763.8 | -1.3 | 779.4 | 14.3 | 15.6 |
| 2022 | 782.4 | 786.4 | 4.0 | 798.2 | 15.7 | 11.8 |
| 2027 | 802.5 | 810.1 | 7.6 | 818.5 | 16.0 | 8.5 |

1/ Normal predicted growth (condition one)

2/ Growth of remaining stand (condition two)

3/ Growth of remaining stand affected by possible changes in abiotic fluxes (condition three)

4/ Mortality caused by chemical defoliation. Volume available for salvage logging.

Salvage Logging Studies

In our 1975 evaluation of the soil conditions following the selective logging of DFTM-infested trees in northeastern Oregon, we found the extent of areas disturbed by tractor logging quite consistent across the five study areas (Tables 31 and 32). Serious soil disturbance ranged from 19.7 percent of the area on Bobsled Ridge to 29.3 percent of the area on Red Saddle. Red Saddle and Kuhn Ridge had the largest area of deep soil disturbance. However, on both these study areas logging residues had been machine-piled in at least part of the study area. It appeared that a large part of the deep disturbance on these two areas was incurred during the residue treatment following logging. Machine piling was used in the Red Saddle area when the soils were quite moist. The soil surface appeared to be compressed and the surface sealed in the most seriously disturbed areas. No significant difference in bulk density was measured between the disturbed surface soil (0.78 gm/cm$^3$) and the nearby undisturbed surface soil (0.71 gm/cm$^3$). However, surface sealing caused by surface compression and organic matter removal appears to have reduced the infiltration capacity so that overland flow may occur during intense rainfall or high snowmelt. Erosion gulleys were observed on the North High Ridge Sale that were caused by surface sealing and water concentration in log skidding trails. Natural seeding may also be impeded in the compressed areas until the surface has been fractured by frost action. Tractor skidding of logs was observed under extremely wet conditions on the Spring Mountain study area.

The extent of deeply disturbed soils in each study area was highly influenced by the depth of the volcanic ash soil and percent slope. Generally, on deep volcanic ash soils tractor turning and log skidding caused considerable disturbance. If the tractor was working on the basalt residium or shallow ash, only slight disturbance occurred. On slopes over 30 percent tractor disturbance was more serious, both from the physical action and the tendency to concentrate skidding on a limited number of trails.

Average plant cover was quite low and reflected the normal understory vegetative cover in this region. The average cover ranged from 16 to 20 percent except in the North High Ridge area. Cover was measured soon after snowmelt and the many annuals found in this area had not developed enough to provide significant ground cover. The recorders were not familiar with all the vegetation species present. However, ninebard (Physocarpus malvaceus), sedges (Carex sp.), myrtle (Pachistima myrsinites) and dwarf blueberry (Vaccinium arbuscula) were frequently observed. It did not appear that logging had any substantial immediate influence on understory vegetation cover in the study areas.

Table 31. Study sites used to evaluate the impact on soils of removing trees damaged by Douglas-fir tussock moth infestation.

| Study Area | Location | Aspect | Slope | Soils | Date Logged | Date Evaluated | Residue Treatmant |
|---|---|---|---|---|---|---|---|
| Red Saddle | T. 1 S., R. 36 E. | Northeast | 0-10 | Medium depth volcanic ash | Fall 1974 | June 1975 | Yes |
| Spring Mountain | T. 1 S., R. 36 E. | West | 10-40 | Deep volcanic ash | Summer 1975 | Sept. 1975 | No |
| Bobsled Ridge | T. 2 N., R. 36 E. | North | 10-30 | Shallow volcanic ash | Summer 1975 | Sept. 1975 | No |
| North High Ridge | T. 3 N., R. 38 E. | Northeast | 0-50 | Deep volcanic ash to rockland | Fall 1974 | June 1975 | No |
| Kuhn Ridge | T. 3N., R. 44 E | South | 0-30 | Medium depth volcanic ash to rockland | Summer 1975 | Sept. 1975 | Yes |

Table 32. Soil surface disturbance and vegetation and logging residue cover for the five study areas.

| Area | Observations | Average area in each disturbance class: Undisturbed (%) | Slight (%) | Severe (%) | Vegetation cover | Residue cover |
|---|---|---|---|---|---|---|
| Red Saddle | 82 | 55.6 | 15.1 | 29.3 | 16.8 | 26.5 |
| North High Ridge | 240 | 51.3 | 23.4 | 25.3 | 4.8 | 37.8 |
| Kuhn Ridge | 232 | 53.7 | 18.2 | 28.1 | 16.9 | 26.9 |
| Bobsled Ridge | 255 | 61.4 | 18.9 | 19.7 | 20.0 | 33.5 |
| Spring Mountain | 590 | 65.5 | 10.0 | 24.5 | 16.0 | 41.0 |
| Total | 1395 | 57.5 | 17.1 | 25.4 | 14.9 | 33.1 |

# CONCLUSIONS

Following chemical defoliation of two nearly 0.4-ha conifer stands in the summer of 1976 to simulate Douglas-fir tussock moth activity, some rather important differences in abiotic fluxes (radiation, heat, water, and nutrients) and possible biologic activity were observed between the defoliated and reference or control stands. These differences measured on our experimental site could influence future stand productivity.

Investigations into use of "fish-eye" 180-degree hemispherical photographs for measuring changes in the forest canopy with defoliation showed that this is an acceptable method for measuring the probable fraction of total solar radiation reaching the forest floor. The probabilities for diffused radiation penetration increased from 21.2 to 28.1 percent and from 19.3 to 35.9 percent following simulated insect defoliation on the two stands, Blocks A and C, respectively. The differential extent of canopy opening and diffused radiation penetration under the same amount of chemical application is attributed to the influence of stand composition and crown structure. The albedo or reflectivity of the forest floor in the defoliated stand was found to be nearly twice that of the reference stands about one month after the defoliation treatment due to the greenish-brown color of the newly fallen needles. The albedo had dropped appreciably one year after treatment, but had not returned to the pre-treatment level. Accounting for changes in albedo and canopy exposure, we estimated that the incoming diffused solar radiation reaching the forest floor averaged 4,985 cal/cm$^2$ greater in Block A and 11,781 cal/cm$^2$ greater in Block C due to defoliation than would have been expected under non-defoliated stand conditions in May 1 to October 31, 1977.

Additional solar energy reaching the forest floor in the defoliated stand is partitioned into fractions heating the air and soil and latent heat of vaporization (evaporation). Energy going into latent heat was not measured. However, differences between the control and defoliated stands are expected to be quite small. Soil and air temperatures were shown to be warmer during the summer months and cooler during the winter period in the defoliated stands. Air temperature increases as large as $6.2^{0}$ C and soil temperature increases of $2.5^{0}$ C at the 2.5-cm depth were observed between the defoliated and control stands. Particularly in Block C, it appears that the energy input going into sensible heating available from increases in canopy exposure exceeded that energy input lost due to increases in the albedo of the forest floor. Differences in soil and air temperatures were not as large in Block A where canopy exposure was not as extensive as in Block C. Air and soil temperatures were lower in the defoliated stands during the winter months due to differences in longwave reradiation and canopy heat capacities. Since the most active period of biologic activity influencing microbiologic activity and possible subsequent plant nutrient availability is during the spring and summer period, lower winter temperatures appear inconsequential in this respect. However, plant physiologic responses, snowmelt, and possibly wildlife activities may be affected.

Evaluations of the air temperature data indicates that maximum differential temperatures between the defoliated and control stands were frequently suppressed by an unmeasured factor. Most likely this factor was wind caused by thermal instability of the air mass immediately above the forest floor being reached quicker in the defoliated stand. Further investigations into this factor are needed.

Simultaneously collected soil temperature and solar radiation data at the experimental site indicates it may take at least a 45 cal/cm$^2$/day increase in the radiation flux reaching the forest floor to increase the 2.5-cm depth soil temperature a measurable 0.1$^{\circ}$ C. This occurs where the canopy exposure as measured by the hemispherical photograph technique has increased 18.3 percent from defoliation. From this information a nomagraph has been developed to predict a soil temperature threshold level relationship between percent canopy defoliation and solar radiation reaching the top of the forest canopy. Thus, for a given level of defoliation the minimum levels of radiation reaching the forest stand which will modify soil temperatures at the 2.5-cm depth can be predicted. This relationship until further testing can only be considered valid for the Nason Creek experimental site.

Amounts of soil water used for evapotranspiration by the control stands were quite similar in 1976 and 1977 although soil water depletion was evident earlier in the spring of 1977. Different rates of soil water depletion in the defoliated stands were observed immediately after chemical defoliation and continued through the remaining summer and fall months. Although precipitation was much less than normal during the winter months of 1976-77, precipitation was adequate to return the soil profiles to "field capacity." In 1977, the soil water depletion rate in the defoliated stands were significantly less from early spring through late August, after which substantial early fall precipitation reduced depletion rates. Differences in the soil water depleted in the upper 1.5 meters of the soil profile between the defoliated and control stands was 12.1 cm in replication one and 14.5 cm in replication two.

Defoliation had a significant influence on the plant nutrient flux rates between the forest canopy and the forest floor. Following defoliation nearly 10 times as much nitrogen as well as other nutrients were returned to the forest floor when compared to the control stands. This additional nitrogen returned to the forest floor over a very short time period by defoliation is equivalent to an approximate 5-year requirement by a mature Douglas-fir stand.

Following defoliation the calcium, magnesium, potassium, phosphorus, and total nitrogen content of the forest floor was increased, reflecting the influence of increased litter fall contribution. Percentage increases in contents for the five nutrients from forest floor sampling averaged 45, 63, 194, 80, and 62, respectively, during the first three months following defoliation. At the same time, defoliation resulted in an average 35 percent increase in forest floor weight. Much of the increase in forest floor nutrient contents following defoliation, for all nutrients except potassium, resulted from the increase in forest floor weight. Increased forest floor potassium contents were also due to addition of fresh litter of much higher relative potassium content than for the previously leached forest floor material. A portion of the needle potassium, and also possibly some of the needle phosphorus, appeared to be leached from the forest floor into the underlying soil during the first overwinter period following defoliation. No other leaching of nutrients from the needles was evident during the study period.

Even though this site was selected for its uniformity, fairly substantial variability existed. This variability was further complicated by the presence of large quantities of decomposing woody material at random locations on the

site, and by mineral contamination of forest floor samples, ranging from 13 to 33 percent by weight. Following adjustment of data for mineral contamination, reasonable trends and averages could be determined. It was concluded that decomposing woody materials should be exclused from attempts to estimate forest floor biomass and nutrient contents associated with defoliation, although nutrient contents of these materials should generally be included as a separate component of aboveground biomass.

Studies of nutrient contents of frass falling beneath feeding Douglas-fir tussock moths indicated that the larvae alter the nutrient content of the needle material. Percentage decreases in potassium, phosphorus, and total nitrogen concentrations of needle material following digestion by tussock moth larvae for this study were 9, 47, and 54, respectively. Percentage increases in calcium and magnesium were 60 and 11, respectively. The decreases probably arose from tussock moth utilization of selected nutrients for their growth processes, whereas the increases could be due to concentration of nonused or slightly used nutrients in larvae digestive tracts. However, there is no evidence that these nutrients utilized by the insect are removed from the site.

No statistically significant changes appeared in the soil nutrient status during the first 15 months following defoliation, and no soil chemical changes of <u>any</u> magnitude were observed during the late summer and early fall months immediately following defoliation. A fairly substantial (though not statistically significant) increase in extractable soil potassium (above the normal overwinter increase evidenced by the control plots) was apparent in the

first growing season following defoliation. There was also a slight increase in soil mineral nitrogen levels of the defoliated plots near the end of the growing season, which may reflect the beginning of a significant upward trend. Further monitoring at the experimental site would be necessary to prove or disprove this postulate, however,

Calcium was the dominant exchangeable cation in the soil, with variations in its sample-to-sample content probably reflecting variations in soil cation exchange capacity. Soil potassium and phosphorus concentrations were found to be lower on sites where a dense understory of vine maple grew. This possibly was related to large uptake of these two nutrients by such understory vegetation. Soil nutrient contents generally decreased with depth in the soil profile, due both to decreasing soil cation exchange capacity (because of decreasing organic matter contents) and to increasing distance from the forest floor nutrient source. Carbon:nitrogen ratios decreased with depth in the soil profile as well, ranging from 26 in the surface 0-3 cm to 18 in the 15-30 cm layer. This probably was related to gradual microbial respiration and loss of $CO_2$, but may also reflect problems with the Walkley-Black procedure in oxidizing resistant organic materials which have leached deeper into the soil profile. Soil pH remained fairly constant with time and depth, at about 5.7.

Despite the possible trend mentioned above, soil mineral nitrogen showed no substantial change in the first 15 months following defoliation. This was probably due to microbial immobilization of defoliated needle nitrogen and to relatively low moisture levels in the forest floor in the late summer and early fall months immediately following defoliation. Even the favorable moisture and temperature relations in the first full growing season following

defoliation did not lead to appreciable microbial release of forest floor nitrogen to the soil mineral nitrogen pool. Only physical and chemical changes (the leaching of some of the potassium and possibly some of the phosphorus, from the forest floor into underlying soil) were in evidence during the study period.

The possible effects of defoliation on the longterm future growth of Blocks A and C were tested with the Stand Prognosis Model for the period 1977 to 2027. The model predicts that under normal stand growth Blocks A and C will increase in volume by 30.7 and 54.9 percent, respectively, in the next 50 years. Where 11 and 21 percent of the present volume is lost to mortality by defoliation in 1977, the volumes of these stands increase by 31.8 and 56.3 percent at the end of 50 years. When we modify the model to account for the possible effects on growth due to changes in the abiotic fluxes as we attempted to measure in our study, volume increases are 32.9 and 58.0 percent for Blocks A and C. Probably more important is the observation that volumes on the defoliated stands equal or exceed that of the unaffected non-defoliated stands in about 35 to 40 years, even with an initial mortality loss of 11 to 21 percent of the volume in the defoliated stands. If we account for possible changes due to the influence of increased nutrient availability following defoliation, volumes are equal or exceed the unaffected stands in 20 to 25 years. Although many factors other than those that can be predicted can affect a stand's growth over a 50-year period in the future, it does appear from the model output that on unmanaged stands defoliation may have some positive effects on a forest site's future productivity.

No observations were made where salvage logging of Douglas-fir tussock moth-affected trees resulted in soil resource damage greater than that observed from "normal" logging in the Oregon Blue Mountain region. There were opportunities where the soil resource could have received better production during logging.

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# APPENDIX A
# SOIL DESCRIPTION

## SOIL DESCRIPTION

**Location:** Nason Creek Area, Chelan County, Washington
T26N, R17E, SE 1/4 of NW 1/4, Sec 7

**Vegetation:** grand fir, Douglas-fir, vine maple

**Elevation:** 640 m

**Average annual precipitation:** 90 cm

**Slope:** 8%, southwest aspect

**Physiography:** Terrace position and foot slope along Nason Creek; material influenced by mountains upland to the north

**Parent material:** Dominated by 95 to 150 cm (+) of material washed from upland residuum and probably some additions of loess

**Drainage:** Well drained

| Depth (cm) | Horizon | Description |
|---|---|---|
| 5-0 | O1 & O2 | Organic matter |
| 0-8 | A1 | Light brownish gray (10YR 6/2) loam; dark grayish brown (10YR 4/2) moist; weak fine platy structure; moist friable, dry slightly hard consistence; roots common; clear, smooth boundary. |
| 8-33 | A2 | Pale brown (10YR 6/3) and brown (10YR 5/3) loam; dark grayish brown (10YR 4/2) and brown to dark brown (10YR 4/3) moist; weak, medium platy and weak, fine subangular blocky structure; moist friable and dry hard consistence; roots common; clear, smooth boundary. |
| 33-53 | B1 | Brown (10YR 5/3) to pale brown (10YR 6/3) sandy loam; dark grayish brown (10YR 4/2) and brown to dark brown (10YR 4/3) moist; weak, medium prismatic breaking to moderate, medium subangular blocky structure; moist firm and dry hard consistence; few discontinuous clay coatings; few roots; gradual, smooth boundary. |

| Depth (cm) | Horizon | Description |
|---|---|---|
| 53-81 | B21t | Brown (10YR 5/3) to pale brown (10YR 6/3) loam; brown to dark brown (10YR 4/3) moist; weak, medium prismatic breaking to moderate, medium subangular blocky structure; moist firm and dry hard consistence; thin, common, discontinuous clay coatings; few roots; vesicular; gradual, smooth boundary. |
| 81-102 | B22t | Yellowish brown (10YR 5/6) clay loam; brown to dark brown (10YR 4/3) moist; weak, medium pismatic breaking to moderate, medium subangular blocky structure; moist firm and dry hard consistency; many clay coatings on ped surfaces; few roots; vesicular; clear, smooth boundary. |
| 102-132 | B23t | Yellowish brown (10YR 5/6) loam; brown to dark brown (10YR 4/3) and dark yellowish brown (10YR 4/4) moist; moderate, coarse angular blocky structure; moist firm and dry hard consistence; many clay coatings; very few roots; vesicular; clear, smooth boundary. |
| 132-158 | B3 | Yellowish brown (10YR 5/6) loam; dark yellowish brown (10YR 4/4) moist; weak, medium subangular blocky structure; moist friable and dry slightly hard consistence; common, moderately thick clay coatings; very few roots; vesicular. |

Comments: a few coarse fragments (< 2%) are scattered throughout the solum. The north and west sides of blocks A and B seem to have a thicker mantle (> 150 cm) of material over glacial drift than the east and southeastern sides (< 100 cm).

Classification: Ultic Haploxeralfs; Fine loamy, mixed, frigid

Description by: Dr. John E. Foss (9/19/75), Professor of Soils, University of Maryland

# APPENDIX B

## TABLES OF FOREST FLOOR CHARACTERISTICS

Table B1--Forest Floor Weights (t/ha)--Non-Adjusted*

| Block | 1975 | | | | 1976 | | | | 1977 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | May | Aug. | Sept. | Oct. | May | June | July | Oct. |
| A | 44 | 42 | 95 | 46 | 56 | 89 | 54 | 57 | 64 | 57 | 72 | |
| B | 52 | 57 | 67 | 43 | 60 | 38 | 29 | 43 | 45 | 61 | 39 | |
| C | ... | 51 | 80 | 43 | 51 | 58 | 47 | 56 | 66 | 57 | 63 | |
| E | ... | 118 | 71 | 36 | 48 | 45 | 39 | 58 | 74 | 59 | 45 | |

Table B2--Forest Floor Weights (t/ha)--Adjusted*

| BLOCK | 1975 | | | | 1976 | | | | 1977 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | May | Aug. | Sept. | Oct. | May | June | July | Oct. |
| A | 44 | 34 | 47 | 46 | 43 | 60 | 54 | 57 | 60 | 50 | 64 | |
| B | 38 | 45 | 50 | 43 | 47 | 38 | 29 | 43 | 45 | 46 | 39 | |
| C | ... | 45 | 48 | 43 | 51 | 58 | 47 | 56 | 57 | 50 | 59 | |
| E | ... | 51 | 57 | 36 | 48 | 45 | 28 | 40 | 51 | 44 | 45 | |

*Adjustment refers to removal of values associated with samples containing decomposing material.

Table B3--Forest Floor Calcium (kg/ha)

| Block | 1975 | | | | 1976 | | | | 1977 | | | | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | May | Aug. | Sept. | Oct. | May | June | July | Oct. | | |
| A | 820 | 1030 | 1720 | 930 | 810 | 1270 | 940 | 1010 | 1110 | 920 | 1140 | | 1320 | 1.0 |
| B | 940 | 1080 | 850 | 690 | 880 | 590 | 470 | 760 | 742 | 1040 | 500 | | 600 | 2.1 |
| C | ..... | 1040 | 1810 | 830 | 820 | 970 | 910 | 1040 | 1100 | 1000 | 1040 | | 1080 | 1.9 |
| E | ..... | 1990 | 1360 | 650 | 710 | 720 | 630 | 700 | 900 | 760 | 570 | | 950 | 5.4 |
| Tukey Value* | | 1140 | 1660 | 470 | 570 | 630 | 530 | 660 | | | | | | |
| F-Test | | 2.4 | 1.0 | 1.1 | 0.2 | 3.3 | 2.6 | 1.0 | | | | | | |

Table B4--Forest Floor Calcium (ppm)

| Block | 1975 | | | | 1976 | | | | 1977 | | | | Values | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | May | Aug. | Sept. | Oct. | May | June | July | Oct. | | |
| A | 23700 | 31000 | 25900 | 24900 | 21400 | 17600 | 20900 | 22000 | 21800 | 19800 | 20400 | | 8800 | 4.0 |
| B | 24200 | 29700 | 21500 | 24100 | 21100 | 19400 | 21200 | 24100 | 23100 | 24300 | 2000 | | 8100 | 2.9 |
| C | ..... | 30200 | 30600 | 28700 | 23200 | 20600 | 22200 | 24000 | 22000 | 20800 | 21700 | | 6100 | 8.4 |
| E | ..... | 25300 | 27300 | 25200 | 19400 | 18600 | 19400 | 16300 | 19200 | 18600 | 18000 | | 7100 | 6.4 |
| Tukey Value* | | 6800 | 7600 | 9000 | 5200 | 4700 | 6100 | 7700 | | | | | | |
| F-Test | | 2.1 | 3.6 | 1.1 | 1.3 | 1.0 | 0.5 | 3.2 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table B5--Forest Floor Magnesium (kg/ha)*

| Block | 1975 | | | | 1976 | | | | 1977 | | | | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | May | Aug. | Sept. | Oct. | May | June | July | Oct. | | |
| A | 72 | 80 | 124 | 66 | 52 | 100 | 73 | 82 | 68 | 69 | 92 | | 74 | 1.7 |
| B | 75 | 122 | 77 | 66 | 60 | 52 | 40 | 63 | 36 | 49 | 39 | | 54 | 4.0 |
| C | .... | 135 | 142 | 84 | 86 | 92 | 74 | 91 | 84 | 71 | 79 | | 76 | 2.2 |
| E | .... | 256 | 172 | 69 | 87 | 71 | 64 | 90 | 86 | 53 | 43 | | 125 | 6.1 |
| Tukey Value* | | 122 | 117 | 36 | 49 | 47 | 48 | 62 | | | | | | |
| F-Test | | 5.5 | 1.7 | 0.8 | 2.0 | 3.1 | 1.6 | 0.6 | | | | | | |

Table B6--Forest Floor Magnesium (ppm)*

| Block | 1975 | | | | 1976 | | | | 1977 | | | | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | May | Aug. | Sept. | Oct. | May | June | July | Oct. | | |
| A | 2210 | 3020 | 2240 | 1890 | 1450 | 1400 | 1720 | 2080 | 1480 | 1090 | 1500 | | 940 | 5.9 |
| B | 2040 | 3320 | 1630 | 2450 | 1600 | 1730 | 1800 | 2290 | 1190 | 1100 | 1770 | | 880 | 8.3 |
| C | .... | 4370 | 2860 | 3180 | 2650 | 2020 | 1910 | 2120 | 1630 | 1540 | 1660 | | 1290 | 8.2 |
| E | .... | 3370 | 3610 | 2730 | 2550 | 1910 | 1940 | 2150 | 1690 | 1410 | 1520 | | 1160 | 6.2 |
| Tukey Value* | | 1280 | 1220 | 1340 | 800 | 360 | 380 | 690 | | | | | | |
| F-Test | | 3.1 | 6.9 | 2.3 | 8.8 | 7.9 | 1.0 | 0.3 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table B7--Forest Floor Potassium (kg/ha)

| Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 48 | 48 | 89 | 51 | 45 | 130 | 115 | 107 | 80 | 73 | 104 | | 63 | 6.1 |
| B | 53 | 58 | 57 | 40 | 50 | 41 | 35 | 45 | 33 | 48 | 34 | | 40 | 0.9 |
| C | .... | 60 | 71 | 45 | 54 | 120 | 109 | 123 | 82 | 84 | 76 | | 62 | 5.4 |
| E | .... | 96 | 69 | 34 | 43 | 45 | 40 | 44 | 43 | 37 | 35 | | 48 | 3.9 |
| Tukey Value* | | 51 | 73 | 33 | 33 | 38 | 43 | 47 | | | | | | |
| F-Test | | 2.5 | 0.5 | 0.7 | 0.3 | 22.3 | 14.4 | 10.9 | | | | | | |

Table B8--Forest Floor Potassium (ppm)

| Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1460 | 1570 | 1460 | 1310 | 1150 | 1960 | 2780 | 2520 | 1580 | 1530 | 1740 | | 610 | 18.4 |
| B | 1390 | 1540 | 1170 | 1330 | 1220 | 1390 | 1560 | 1640 | 1060 | 1040 | 1320 | | 360 | 4.0 |
| C | .... | 1750 | 1280 | 1520 | 1450 | 2670 | 2810 | 2820 | 1520 | 1630 | 1610 | | 470 | 39.7 |
| E | .... | 1270 | 1400 | 1300 | 1240 | 1230 | 1350 | 1210 | 910 | 930 | 1140 | | 370 | 0.7 |
| Tukey Value* | | 370 | 390 | 400 | 270 | 370 | 610 | 390 | | | | | | |
| F-Test | | 4.1 | 1.6 | 1.0 | 3.3 | 44.0 | 23.1 | 54.4 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table B9--Forest Floor Phosphorus (kg/ha)

| Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 33 | 40 | 73 | 34 | 45 | 76 | 64 | 67 | 50 | 57 | 69 | | 50 | 2.5 |
| B | 38 | 47 | 66 | 32 | 54 | 34 | 27 | 42 | 41 | 51 | 35 | | 34 | 2.7 |
| C | .... | 44 | 50 | 31 | 50 | 55 | 50 | 58 | 65 | 57 | 59 | | 37 | 1.1 |
| E | .... | 75 | 45 | 25 | 40 | 39 | 33 | 37 | 42 | 48 | 36 | | 36 | 3.6 |
| Tukey Value* | | 40 | 58 | 25 | 29 | 29 | 26 | 27 | | | | | | |
| F-Test | | 2.3 | 0.8 | 0.3 | 0.6 | 6.0 | 6.3 | 3.8 | | | | | | |

Table B10--Forest Floor Phosphorus (ppm)

| Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 1030 | 1370 | 1190 | 810 | 1280 | 1150 | 1500 | 1600 | 1080 | 1250 | 1270 | | 410 | 7.6 |
| B | 1020 | 1340 | 1430 | 1110 | 1410 | 1150 | 1240 | 1510 | 1340 | 1240 | 1540 | | 440 | 3.0 |
| C | .... | 1250 | 990 | 1090 | 1440 | 1210 | 1260 | 1320 | 1260 | 1170 | 1230 | | 330 | 2.7 |
| E | .... | 1020 | 940 | 1000 | 1210 | 1060 | 1090 | 1070 | 910 | 1200 | 1130 | | 290 | 1.6 |
| Tukey Value* | | 340 | 330 | 410 | 360 | 260 | 200 | 330 | | | | | | |
| F-Test | | 3.1 | 6.6 | 1.7 | 1.3 | 0.8 | 10.6 | 7.1 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table B11--Forest Floor Nitrogen (kg/ha)

| Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 403 | 394 | 850 | 339 | 413 | 668 | 490 | 517 | 569 | 539 | 626 | | 577 | 1.7 |
| B | 467 | 438 | 478 | 289 | 423 | 302 | 238 | 343 | 359 | 438 | 313 | | 327 | 1.5 |
| C | ... | 419 | 707 | 335 | 413 | 489 | 454 | 520 | 606 | 570 | 595 | | 497 | 1.0 |
| E | ... | 774 | 552 | 312 | 282 | 400 | 341 | 405 | 459 | 431 | 388 | | 388 | 3.2 |
| Tukey Value* | | 408 | 788 | 187 | 279 | 277 | 232 | 300 | | | | | | |
| F-Test | | 2.8 | 0.6 | 0.2 | 0.1 | 4.6 | 3.5 | 1.2 | | | | | | |

Table B12--Forest Floor Nitrogen (ppm)

| Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 11900 | 12700 | 11900 | 9300 | 11100 | 9400 | 11200 | 11700 | 11900 | 11600 | 11500 | | 2470 | 4.7 |
| B | 11200 | 11500 | 11100 | 9400 | 10000 | 10000 | 10700 | 11400 | 12400 | 10100 | 12100 | | 2020 | 2.9 |
| C | ..... | 12600 | 11400 | 11400 | 11300 | 10600 | 11200 | 11500 | 12700 | 11900 | 12500 | | 2150 | 1.5 |
| E | ..... | 10400 | 11400 | 12100 | 11000 | 11000 | 11600 | 10900 | 9900 | 10500 | 11700 | | 2680 | 0.8 |
| Tukey Value* | | 2160 | 2110 | 3040 | 2050 | 1980 | 1310 | 1590 | | | | | | |
| F-Test | | 3.6 | 0.3 | 3.3 | 1.2 | 1.9 | 1.1 | 0.7 | | | | | | |

*All Tukey values are calculated at the 5% level.

# APPENDIX C

## TABLES OF SOIL CHARACTERISTICS

Table C1--Soil Moisture Percentage (%)

| Depth (cm) | Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 June | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Sept. | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A | 26.8 | 17.2 | 22.8 | 15.3 | 52.1 | 25.7 | 27.4 | 22.7 | 12.2 | 36.2 | 36.9 | 24.7 | 17.0 | 24.7 | 13.3 | 15.2 |
| | B | 19.6 | 13.9 | 19.1 | 12.4 | 37.2 | 17.3 | 22.4 | 13.5 | 9.4 | 24.0 | 24.8 | 8.7 | 7.4 | 15.0 | 8.2 | 20.5 |
| | C | .... | 12.1 | 20.6 | 17.1 | 43.8 | 20.6 | 23.1 | 22.1 | 12.3 | 35.1 | 43.5 | 14.9 | 18.3 | 28.0 | 15.0 | 8.3 |
| | E | .... | 11.7 | 21.0 | 15.4 | 43.4 | 17.1 | 19.3 | 17.7 | 11.0 | 30.4 | 23.6 | 8.0 | 8.4 | 18.6 | 12.0 | 14.1 |
| | Tukey Value* | | 3.0 | 6.2 | 6.0 | 16.3 | 5.6 | 6.9 | 7.6 | 3.5 | | | | | | | |
| | F-Test | | 4.8 | 0.5 | 0.9 | 1.2 | 4.2 | 1.9 | 2.6 | 1.3 | | | | | | | |
| 3-7.5 | A | 20.4 | 15.3 | 16.7 | 13.9 | 29.2 | 16.9 | 16.4 | 15.2 | 12.0 | 28.2 | 25.1 | 18.9 | 20.4 | 19.6 | 5.9 | 14.4 |
| | B | 17.0 | 12.4 | 16.6 | 12.0 | 25.0 | 16.1 | 15.2 | 11.6 | 9.2 | 24.1 | 19.2 | 9.1 | 9.7 | 13.1 | 3.7 | 31.7 |
| | C | .... | 11.0 | 12.5 | 11.3 | 28.4 | 16.5 | 16.0 | 14.0 | 11.0 | 25.5 | 24.8 | 12.9 | 15.9 | 20.3 | 5.2 | 24.2 |
| | E | .... | 11.8 | 14.8 | 10.8 | 26.2 | 14.1 | 12.9 | 10.1 | 9.0 | 22.9 | 21.0 | 9.2 | 9.0 | 13.2 | 4.1 | 34.2 |
| | Tukey Value* | | 2.3 | 2.9 | 2.8 | 3.7 | 3.1 | 4.0 | 2.2 | 1.6 | | | | | | | |
| | F-Test | | 5.4 | 4.0 | 2.0 | 2.3 | 1.4 | 1.3 | 9.4 | 6.5 | | | | | | | |
| 7.5-15 | A | 17.6 | 14.4 | 16.0 | 15.2 | 26.2 | 16.1 | 15.3 | 14.9 | 11.2 | 24.6 | 25.8 | 19.7 | 19.5 | 17.9 | 5.2 | 12.6 |
| | B | 15.0 | 11.6 | 14.6 | 11.0 | 24.1 | 15.4 | 13.7 | 10.6 | 8.9 | 21.3 | 17.9 | 9.8 | 9.9 | 16.3 | 2.8 | 52.4 |
| | C | .... | 11.2 | 13.0 | 10.9 | 25.5 | 15.8 | 13.6 | 12.8 | 10.9 | 25.1 | 22.5 | 12.8 | 17.9 | 18.9 | 4.4 | 22.9 |
| | E | .... | 10.8 | 14.2 | 10.4 | 24.8 | 13.4 | 11.3 | 9.4 | 8.3 | 20.1 | 16.0 | 8.7 | 8.3 | 10.8 | 3.7 | 38.9 |
| | Tukey Value* | | 1.9 | 2.8 | 4.0 | 3.8 | 2.2 | 2.4 | 1.8 | 1.3 | | | | | | | |
| | F-Test | | 5.7 | 1.5 | 2.6 | 0.5 | 2.5 | 4.0 | 14.8 | 10.3 | | | | | | | |
| 15-30 | A | 16.4 | 13.0 | 13.6 | 10.5 | 22.6 | 15.5 | 13.4 | 12.3 | 11.2 | 22.0 | 21.6 | 15.8 | 17.0 | 15.8 | 3.0 | 30.2 |
| | B | 14.0 | 11.0 | 13.2 | 10.0 | 21.0 | 14.3 | 12.0 | 10.1 | 9.1 | 19.0 | 15.4 | 9.3 | 9.8 | 9.9 | 2.4 | 48.0 |
| | C | .... | 10.0 | 12.0 | 9.8 | 22.5 | 14.1 | 11.3 | 11.4 | 10.1 | 21.0 | 19.5 | 10.9 | 14.1 | 16.6 | 2.7 | 46.3 |
| | E | .... | 9.7 | 14.6 | 8.2 | 20.0 | 13.3 | 10.0 | 8.8 | 7.7 | 18.0 | 14.7 | 8.1 | 8.6 | 9.6 | 4.5 | 17.1 |
| | Tukey Value* | | 1.5 | 4.2 | 1.2 | 1.9 | 1.6 | 1.8 | 1.7 | 1.2 | | | | | | | |
| | F-Test | | 8.3 | 0.6 | 5.8 | 3.6 | 2.9 | 5.2 | 6.5 | 13.4 | | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C2--Extractable Soil Calcium (ppm)

| Depth (cm) | Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A | 2750 | 2870 | 2440 | 2640 | 3060 | 2480 | 2630 | 3000 | 2580 | 2800 | 2730 | 3030 | 1210 | 0.7 |
| | B | 1830 | 2150 | 2020 | 2420 | 2850 | 2460 | 2160 | 2530 | 2440 | 2550 | 2530 | 2730 | 940 | 2.3 |
| | C | .... | 1760 | 2150 | 2310 | 2890 | 2890 | 2220 | 2190 | 2500 | 2740 | 2580 | 2260 | 610 | 8.3 |
| | E | .... | 1830 | 2070 | 2210 | 3110 | 2510 | 2440 | 2530 | 2440 | 2480 | 2390 | 2360 | 730 | 5.8 |
| | Tukey Value* | | 570 | 460 | 570 | 630 | 630 | 510 | 630 | | | | | | |
| | F-Test | | 6.5 | 1.4 | 0.9 | 0.3 | 0.8 | 1.4 | 2.3 | | | | | | |
| 3-7.5 | A | 1810 | 2010 | 1880 | 1940 | 2310 | 1780 | 1900 | 2340 | 1920 | 1980 | 1950 | 2480 | 600 | 2.4 |
| | B | 1320 | 1470 | 1470 | 1730 | 1980 | 1480 | 1510 | 1910 | 1550 | 1750 | 1730 | 1770 | 520 | 4.0 |
| | C | .... | 1190 | 1590 | 1660 | 2130 | 1760 | 1630 | 1770 | 1810 | 1860 | 2170 | 1640 | 400 | 9.0 |
| | E | .... | 1610 | 1690 | 1540 | 2330 | 1830 | 1760 | 2170 | 1850 | 1750 | 1930 | 1730 | 440 | 6.6 |
| | Tukey Value* | | 290 | 280 | 390 | 370 | 350 | 260 | 360 | | | | | | |
| | F-Test | | 11.1 | 3.1 | 1.5 | 1.6 | 1.7 | 3.4 | 4.2 | | | | | | |
| 7.5-15 | A | 1600 | 1750 | 1700 | 1750 | 2120 | 1700 | 1700 | 2180 | 1710 | 1755 | 1742 | 1982 | 450 | 4.4 |
| | B | 1240 | 1360 | 1320 | 1530 | 1730 | 1400 | 1310 | 1780 | 1240 | 1516 | 1594 | 1530 | 410 | 4.7 |
| | C | .... | 1120 | 1450 | 1430 | 1900 | 1490 | 1440 | 1560 | 1550 | 1652 | 1611 | 1425 | 280 | 12.4 |
| | E | .... | 1390 | 1580 | 1540 | 2090 | 1600 | 1570 | 1940 | 1640 | 1601 | 1708 | 1594 | 410 | 6.6 |
| | Tukey Value* | | 210 | 190 | 290 | 260 | 270 | 200 | 340 | | | | | | |
| | F-Test | | 12.2 | 6.1 | 1.8 | 3.8 | 1.9 | 5.9 | 4.8 | | | | | | |
| 15-30 | A | 1500 | 1600 | 1750 | 1630 | 1900 | 1810 | 1700 | 2150 | 1590 | 1689 | 1678 | 1840 | 480 | 3.6 |
| | B | 1270 | 1370 | 1360 | 1430 | 1700 | 1420 | 1260 | 1640 | 1320 | 1352 | 1554 | 1427 | 360 | 3.8 |
| | C | .... | 990 | 1250 | 1280 | 1530 | 1270 | 1390 | 1370 | 1410 | 1353 | 1382 | 1332 | 230 | 9.5 |
| | E | .... | 1270 | 1490 | 1380 | 1760 | 1410 | 1440 | 1710 | 1400 | 1485 | 1503 | 1467 | 320 | 5.8 |
| | Tukey Value* | | 170 | 170 | 170 | 250 | 220 | 240 | 380 | | | | | | |
| | F-Test | | 17.6 | 12.8 | 5.9 | 3.1 | 8.9 | 4.7 | 5.8 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C3--Extractable Soil Magnesium (ppm)

| Depth (cm) | Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A | 240 | 232 | 204 | 230 | 265 | 257 | 228 | 251 | 236 | 238 | 219 | 258 | 71 | 1.4 |
| | B | 164 | 155 | 161 | 177 | 207 | 189 | 173 | 212 | 188 | 187 | 182 | 197 | 49 | 3.5 |
| | C | ... | 235 | 268 | 305 | 344 | 319 | 282 | 300 | 267 | 304 | 270 | 266 | 63 | 5.8 |
| | E | ... | 301 | 339 | 385 | 434 | 350 | 375 | 369 | 365 | 342 | 324 | 369 | 123 | 2.1 |
| | Tukey Value* | | 47 | 48 | 55 | 60 | 57 | 59 | 45 | | | | | | |
| | F-Test | | 12.9 | 21.7 | 22.0 | 22.0 | 12.9 | 17.2 | 18.8 | | | | | | |
| 3-7.5 | A | 219 | 211 | 200 | 209 | 240 | 207 | 192 | 246 | 208 | 223 | 203 | 210 | 56 | 2.2 |
| | B | 149 | 141 | 155 | 152 | 192 | 154 | 153 | 212 | 159 | 155 | 173 | 162 | 45 | 5.8 |
| | C | ... | 207 | 235 | 254 | 306 | 261 | 246 | 293 | 229 | 258 | 219 | 252 | 49 | 8.8 |
| | E | ... | 280 | 310 | 314 | 371 | 298 | 308 | 349 | 310 | 297 | 295 | 304 | 100 | 1.8 |
| | Tukey Value* | | 42 | 37 | 48 | 43 | 39 | 49 | 44 | | | | | | |
| | F-Test | | 14.9 | 25.1 | 16.7 | 26.4 | 21.8 | 15.3 | 15.2 | | | | | | |
| 7.5-15 | A | 220 | 210 | 207 | 201 | 239 | 198 | 196 | 263 | 203 | 223 | 204 | 202 | 60 | 2.9 |
| | B | 153 | 148 | 155 | 150 | 197 | 148 | 155 | 213 | 154 | 151 | 156 | 161 | 43 | 6.9 |
| | C | ... | 205 | 228 | 227 | 298 | 238 | 229 | 271 | 226 | 255 | 211 | 230 | 50 | 7.1 |
| | E | ... | 255 | 298 | 302 | 351 | 278 | 267 | 335 | 295 | 291 | 272 | 293 | 80 | 3.6 |
| | Tukey Value* | | 35 | 37 | 40 | 46 | 32 | 36 | 48 | | | | | | |
| | F-Test | | 12.9 | 21.3 | 20.6 | 17.4 | 25.1 | 14.7 | 8.9 | | | | | | |
| 15-30 | A | 211 | 200 | 213 | 197 | 230 | 222 | 196 | 253 | 200 | 213 | 207 | 202 | 62 | |
| | B | 167 | 159 | 164 | 151 | 204 | 151 | 157 | 205 | 157 | 150 | 164 | 158 | 47 | 4.4 |
| | C | ... | 200 | 211 | 218 | 265 | 221 | 222 | 264 | 220 | 244 | 206 | 223 | 39 | 7.9 |
| | E | ... | 254 | 287 | 271 | 321 | 268 | 259 | 317 | 285 | 281 | 256 | 280 | 66 | 3.1 |
| | Tukey Value* | | 30 | 37 | 32 | 40 | 34 | 31 | 46 | | | | | | |
| | F-Test | | 14.4 | 15.3 | 20.4 | 13.0 | 16.7 | 15.9 | 8.1 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C4--Extractable Soil Potassium (ppm)

| Depth (cm) | Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A | 324 | 356 | 304 | 337 | 308 | 378 | 320 | 319 | 404 | 378 | 427 | 436 | 165 | 0.4 |
| | B | 292 | 305 | 290 | 328 | 310 | 328 | 321 | 311 | 340 | 359 | 308 | 370 | 127 | 0.3 |
| | C | ... | 204 | 197 | 251 | 241 | 270 | 215 | 242 | 285 | 311 | 287 | 258 | 83 | 1.9 |
| | E | ... | 158 | 155 | 224 | 207 | 182 | 194 | 180 | 196 | 203 | 242 | 211 | 67 | 2.5 |
| | Tukey Value* | | 86 | 69 | 87 | 66 | 82 | 69 | 70 | | | | | | |
| | F-Test | | 9.1 | 8.9 | 3.3 | 4.9 | 8.7 | 7.8 | 7.1 | | | | | | |
| 3-7.5 | A | 283 | 317 | 283 | 293 | 304 | 320 | 293 | 301 | 320 | 308 | 381 | 339 | 122 | 0.3 |
| | B | 261 | 275 | 267 | 292 | 301 | 283 | 267 | 287 | 301 | 299 | 276 | 323 | 113 | 0.3 |
| | C | ... | 174 | 168 | 186 | 198 | 192 | 179 | 203 | 200 | 217 | 196 | 209 | | |
| | E | ... | 135 | 139 | 176 | 166 | 153 | 145 | 151 | 167 | 162 | 184 | 167 | 48 | 1.7 |
| | Tukey Value* | | 65 | 60 | 64 | 60 | 54 | 49 | 60 | | | | | | |
| | F-Test | | 14.1 | 11.5 | 8.3 | 11.4 | 17.1 | 17.1 | 11.5 | | | | | | |
| 7.5-15 | A | 264 | 292 | 264 | 269 | 291 | 307 | 299 | 304 | 306 | 278 | 346 | 319 | 108 | 0.5 |
| | B | 267 | 258 | 274 | 258 | 282 | 263 | 270 | 305 | 289 | 298 | 270 | 288 | 108 | 0.4 |
| | C | ... | 172 | 153 | 169 | 172 | 166 | 164 | 190 | 181 | 179 | 168 | 186 | 38 | 1.6 |
| | E | ... | 133 | 132 | 151 | 154 | 145 | 132 | 140 | 149 | 146 | 160 | 151 | 36 | 1.2 |
| | Tukey Value* | | 53 | 47 | 50 | 46 | 58 | 45 | 67 | | | | | | |
| | F-Test | | 15.6 | 19.7 | 11.7 | 20.0 | 14.4 | 25.8 | 12.6 | | | | | | |
| 15-30 | A | 256 | 292 | 259 | 273 | 264 | 293 | 281 | 298 | 291 | 277 | 336 | 299 | 82 | 0.8 |
| | B | 245 | 259 | 261 | 243 | 270 | 268 | 252 | 305 | 275 | 285 | 279 | 265 | 84 | 1.1 |
| | C | ... | 156 | 152 | 162 | 162 | 159 | 161 | 162 | 190 | 169 | 157 | 176 | 31 | 0.3 |
| | E | ... | 127 | 124 | 138 | 143 | 139 | 128 | 138 | 136 | 134 | 147 | 142 | 31 | 1.0 |
| | Tukey Value* | | 37 | 33 | 44 | 33 | 46 | 34 | 54 | | | | | | |
| | F-Test | | 36.9 | 37.2 | 17.4 | 33.6 | 23.5 | 38.2 | 21.3 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C5--Extractable Soil Phosphorus (ppm)

| Depth (cm) | Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A | 19.1 | 25.9 | 19.8 | 19.3 | 19.9 | 17.8 | 20.5 | 17.2 | 21.3 | 25.4 | 20.4 | 28.1 | 12.2 | .9 |
| | B | 19.3 | 21.1 | 20.8 | 20.7 | 23.1 | 19.7 | 20.4 | 21.4 | 19.1 | 22.8 | 21.2 | 23.4 | 9.0 | .3 |
| | C | .... | 9.5 | 14.1 | 13.7 | 15.9 | 20.0 | 13.6 | 14.4 | 18.5 | 20.3 | 18.5 | 15.1 | 6.9 | 3.8 |
| | E | .... | 14.3 | 13.9 | 14.0 | 16.3 | 15.0 | 17.4 | 12.9 | 15.4 | 13.9 | 18.9 | 14.6 | 5.1 | 1.7 |
| | Tukey Value* | | 9.3 | 5.2 | 4.0 | 5.8 | 4.8 | 4.5 | 5.6 | | | | | | |
| | F-Test | | 5.0 | 4.1 | 6.7 | 2.8 | 1.9 | 4.2 | 3.6 | | | | | | |
| 3-7.5 | A | 16.2 | 15.4 | 14.8 | 15.5 | 16.1 | 14.2 | 14.5 | 14.1 | 15.5 | 15.4 | 14.9 | 16.2 | 6.5 | .3 |
| | B | 15.8 | 17.0 | 17.5 | 19.1 | 20.2 | 16.4 | 17.9 | 17.8 | 16.5 | 16.8 | 16.3 | 18.5 | 7.2 | .8 |
| | C | .... | 7.0 | 9.8 | 9.8 | 10.8 | 13.1 | 10.2 | 10.0 | 11.6 | 12.9 | 13.2 | 10.9 | 4.3 | 3.2 |
| | E | .... | 10.6 | 10.7 | 11.5 | 12.1 | 11.0 | 12.4 | 9.8 | 11.3 | 10.0 | 14.7 | 10.6 | 4.4 | .8 |
| | Tukey Value* | | 3.2 | 3.7 | 3.4 | 3.9 | 3.9 | 3.7 | 3.8 | | | | | | |
| | F-Test | | 16.3 | 7.8 | 11.8 | 9.6 | 2.7 | 6.6 | 8.1 | | | | | | |
| 7.5-15 | A | 14.4 | 13.5 | 13.9 | 13.6 | 14.2 | 12.4 | 12.7 | 14.2 | 14.2 | 13.3 | 13.0 | 13.2 | 5.7 | .3 |
| | B | 15.2 | 14.9 | 17.8 | 17.7 | 18.3 | 15.4 | 17.5 | 17.1 | 16.2 | 16.8 | 15.1 | 15.7 | 5.8 | 1.0 |
| | C | .... | 7.5 | 8.4 | 8.8 | 9.3 | 9.9 | 9.0 | 9.7 | 10.6 | 10.8 | 11.0 | 9.4 | 3.8 | .9 |
| | E | .... | 9.3 | 9.7 | 10.1 | 9.8 | 10.0 | 10.9 | 8.8 | 10.6 | 9.6 | 11.5 | 9.4 | 3.7 | .6 |
| | Tukey Value* | | 2.8 | 3.6 | 2.9 | 3.1 | 2.8 | 3.2 | 3.3 | | | | | | |
| | F-Test | | 12.7 | 11.7 | 15.3 | 14.9 | 7.2 | 10.4 | 11.6 | | | | | | |
| 15-30 | A | 14.4 | 13.5 | 13.9 | 13.6 | 14.5 | 13.9 | 13.4 | 15.2 | 13.4 | 13.3 | 12.6 | 13.2 | 5.4 | .3 |
| | B | 13.8 | 16.1 | 18.1 | 18.0 | 19.2 | 17.5 | 18.8 | 17.8 | 17.2 | 17.1 | 15.9 | 15.2 | 5.4 | 2.0 |
| | C | .... | 5.7 | 7.9 | 7.2 | 7.0 | 8.5 | 8.5 | 8.7 | 9.1 | 8.8 | 8.8 | 8.9 | 3.3 | 2.0 |
| | E | .... | 7.2 | 7.5 | 7.3 | 8.8 | 7.5 | 8.7 | 7.4 | 8.6 | 7.8 | 9.0 | 8.3 | 3.1 | .9 |
| | Tukey Value* | | 2.5 | 3.1 | 2.9 | 3.4 | 2.8 | 2.6 | 3.3 | | | | | | |
| | F-Test | | 33.0 | 20.0 | 26.7 | 21.6 | 23.0 | 29.7 | 18.6 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C6--Total Soil Nitrogen (ppm)

| Depth (cm) | Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A | 2220 | 1530 | 1280 | 1280 | 1760 | 1600 | 1720 | 1120 | 1940 | 1420 | 930 | | 1200 | 2.4 |
| | B | 1380 | 1170 | 1190 | 1180 | 1350 | 1740 | 1560 | 1170 | 1950 | 1800 | 1370 | | 840 | 1.0 |
| | C | .... | 1320 | 1170 | 1490 | 1630 | 2200 | 1410 | 1390 | 1920 | 1690 | 1450 | | 1040 | 3.4 |
| | E | .... | 940 | 1020 | 1040 | 1290 | 1260 | 1650 | 1190 | 990 | 1160 | 1520 | | 840 | 1.0 |
| | Tukey Value* | | 550 | 380 | 510 | 560 | 840 | 500 | 340 | | | | | | |
| | F-Test | | 1.6 | 0.7 | 1.1 | 1.3 | 1.2 | 1.1 | 1.0 | | | | | | |
| 3-7.5 | A | 730 | 840 | 740 | 730 | 920 | 750 | 840 | 760 | 870 | 700 | 560 | | 460 | 0.6 |
| | B | 830 | 680 | 710 | 760 | 800 | 870 | 680 | 690 | 830 | 860 | 780 | | 310 | 1.0 |
| | C | .... | 780 | 690 | 800 | 1000 | 1000 | 880 | 850 | 1130 | 820 | 660 | | 520 | 0.8 |
| | E | .... | 630 | 600 | 620 | 810 | 680 | 660 | 760 | 530 | 460 | 870 | | 360 | 0.8 |
| | Tukey Value* | | 360 | 170 | 430 | 240 | 310 | 320 | 150 | | | | | | |
| | F-Test | | 0.6 | 1.0 | 0.3 | 1.4 | 1.4 | 0.8 | 1.6 | | | | | | |
| 7.5-15 | A | 610 | 590 | 560 | 520 | 640 | 620 | 670 | 580 | 630 | 520 | 430 | | 290 | 0.3 |
| | B | 540 | 540 | 530 | 690 | 560 | 680 | 530 | 680 | 620 | 660 | 590 | | 350 | 1.0 |
| | C | .... | 670 | 550 | 700 | 790 | 870 | 720 | 820 | 750 | 670 | 550 | | 400 | 1.6 |
| | E | .... | 520 | 500 | 520 | 670 | 610 | 420 | 600 | 360 | 460 | 540 | | 280 | 1.8 |
| | Tukey Value* | | 280 | 120 | 200 | 140 | 200 | 210 | 220 | | | | | | |
| | F-Test | | 0.4 | 0.3 | 2.0 | 4.1 | 3.6 | 3.1 | 1.9 | | | | | | |
| 15-30 | A | 430 | 400 | 350 | 370 | 360 | 520 | 600 | 410 | 410 | 350 | 160 | | 330 | 2.6 |
| | B | 350 | 310 | 370 | 360 | 470 | 460 | 330 | 460 | 440 | 490 | 430 | | 290 | 0.8 |
| | C | .... | 420 | 430 | 380 | 530 | 610 | 480 | 580 | 500 | 470 | 350 | | 300 | 1.5 |
| | E | .... | 360 | 360 | 390 | 420 | 430 | 430 | 430 | 350 | 330 | 330 | | 250 | 0.2 |
| | Tukey Value* | | 150 | 110 | 110 | 200 | 100 | 100 | 140 | | | | | | |
| | F-Test | | 0.8 | 0.7 | 0.1 | 1.0 | 5.1 | 5.3 | 2.4 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C7--Soil pH

| Depth (cm) | Block | 1975 July | 1975 Aug. | 1975 Sept. | 1975 Oct. | 1976 May | 1976 Aug. | 1976 Sept. | 1976 Oct. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-3 | A | 5.7 | 5.6 | 5.8 | 5.5 | 5.8 | 5.5 | 5.7 | 6.0 | 5.9 | 6.0 | 6.3 | 6.1 | 0.6 | 1.7 |
| | B | 5.7 | 5.4 | 5.7 | 5.7 | 6.1 | 5.6 | 5.9 | 6.1 | 5.9 | 5.8 | 5.8 | 6.0 | 0.6 | 3.4 |
| | C | ... | 5.6 | 5.6 | 5.4 | 5.8 | 5.6 | 5.8 | 5.9 | 6.0 | 5.9 | 5.6 | 6.1 | 0.4 | 3.0 |
| | E | ... | 5.7 | 5.6 | 5.4 | 5.9 | 5.7 | 5.5 | 5.8 | 6.0 | 5.9 | 5.5 | 5.8 | 0.4 | 3.5 |
| | Tukey Value* | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.2 | | | | | | |
| | F-Test | | 0.8 | 1.2 | 1.0 | 1.8 | 0.5 | 1.6 | 1.8 | | | | | | |
| 3-7.5 | A | 5.8 | 5.8 | 5.8 | 5.6 | 5.8 | 5.7 | 5.8 | 6.0 | 5.8 | 6.0 | 6.2 | 6.1 | 0.6 | 0.5 |
| | B | 5.7 | 5.5 | 5.7 | 5.8 | 6.0 | 5.6 | 5.8 | 6.1 | 5.7 | 5.8 | 5.8 | 6.0 | 0.5 | 2.6 |
| | C | ... | 5.6 | 5.7 | 5.5 | 5.7 | 5.6 | 5.7 | 5.8 | 5.9 | 6.0 | 5.6 | 5.8 | 0.4 | 1.4 |
| | E | ... | 5.8 | 5.7 | 5.5 | 5.9 | 5.8 | 5.7 | 5.9 | 6.1 | 6.1 | 5.5 | 5.9 | 0.4 | 3.4 |
| | Tukey Value* | | 0.3 | 0.4 | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 | | | | | | |
| | F-Test | | 1.4 | 0.2 | 1.7 | 1.3 | 1.2 | 0.2 | 1.9 | | | | | | |
| 7.5-15 | A | 5.8 | 5.8 | 5.9 | 5.7 | 5.7 | 5.8 | 5.7 | 6.0 | 5.8 | 5.9 | 6.1 | 6.0 | 0.5 | 0.9 |
| | B | 5.8 | 5.6 | 5.8 | 5.7 | 5.9 | 5.7 | 5.7 | 6.1 | 5.8 | 5.8 | 5.9 | 5.9 | 0.5 | 2.0 |
| | C | ... | 5.7 | 5.7 | 5.5 | 5.7 | 5.6 | 5.7 | 5.7 | 5.9 | 6.0 | 5.6 | 5.7 | 0.4 | 0.8 |
| | E | ... | 5.8 | 5.7 | 5.6 | 5.7 | 5.8 | 5.7 | 5.9 | 6.0 | 5.9 | 5.6 | 5.6 | 0.3 | 2.8 |
| | Tukey Value* | | 0.3 | 0.2 | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 | | | | | | |
| | F-Test | | 0.8 | 0.8 | 0.9 | 2.2 | 1.1 | 0.1 | 3.4 | | | | | | |
| 15-30 | A | 5.7 | 5.6 | 5.8 | 5.7 | 5.6 | 5.8 | 5.8 | 5.9 | 5.3 | 5.8 | 5.9 | 6.0 | 0.4 | 1.1 |
| | B | 5.8 | 5.7 | 5.7 | 5.8 | 5.8 | 5.7 | 5.7 | 5.9 | 5.7 | 5.7 | 5.9 | 5.9 | 0.4 | 0.7 |
| | C | ... | 5.6 | 5.7 | 5.6 | 5.6 | 5.5 | 5.7 | 5.8 | 5.9 | 5.8 | 5.5 | 5.6 | 0.3 | 1.2 |
| | E | ... | 5.8 | 5.8 | 5.6 | 5.8 | 5.7 | 5.6 | 5.8 | 5.9 | 5.9 | 5.6 | 5.5 | 0.2 | 0.0 |
| | Tukey Value* | | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | | | | | |
| | F-Test | | 1.0 | 0.4 | 0.8 | 1.6 | 1.0 | 0.7 | 1.4 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C8--Oxidizable Material (%)

| Depth (cm) | Block | 1975 Sept. | 1975 Oct. | 1976 Aug. | 1976 Sept. | 1977 May | 1977 June | 1977 July | 1977 Oct. | Tukey Value | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | 4.4 | 5.8 | 7.4 | 6.9 | 7.4 | 7.8 | 6.1 | 8.7 | 2.1 | 3.1 |
| | B | 4.8 | 5.4 | 8.6 | 6.0 | 6.8 | 7.0 | 7.5 | 6.0 | 2.4 | 4.1 |
| 0-3 | C | 5.4 | 6.1 | 9.3 | 6.8 | 6.4 | 8.7 | 7.4 | 5.3 | 7.0 | 2.5 |
| | E | 4.2 | 5.6 | 6.3 | 8.1 | 6.5 | 5.2 | 6.7 | 7.1 | 2.8 | 2.8 |
| | Tukey Value* | 1.6 | 1.3 | 3.5 | 3.3 | | | | | | |
| | F-Test | 0.8 | 0.4 | 1.2 | 0.6 | | | | | | |
| | A | 2.8 | 3.2 | 3.0 | 3.0 | 3.4 | 3.3 | 2.9 | 3.4 | 0.9 | 0.3 |
| | B | 2.7 | 3.1 | 3.5 | 3.1 | 3.0 | 3.6 | 3.3 | 3.2 | 0.7 | 2.0 |
| 3-7.5 | C | 2.9 | 4.1 | 3.8 | 3.4 | 3.8 | 3.7 | 3.1 | 3.5 | 1.7 | 0.8 |
| | E | 2.6 | 2.8 | 3.5 | 2.8 | 2.7 | 2.4 | 3.5 | 3.2 | 1.4 | 0.6 |
| | Tukey Value* | 0.9 | 1.4 | 1.6 | 0.8 | | | | | | |
| | F-Test | 0.2 | 1.3 | 0.4 | 0.8 | | | | | | |
| | A | 1.7 | 2.2 | 2.1 | 2.1 | 2.1 | 2.2 | 1.9 | 2.3 | 0.5 | 1.7 |
| | B | 1.8 | 2.5 | 2.4 | 2.4 | 1.8 | 2.4 | 2.1 | 2.5 | 0.6 | 2.1 |
| 7.5-15 | C | 2.1 | 2.7 | 2.8 | 2.6 | 2.6 | 2.6 | 2.2 | 2.5 | 0.6 | 2.6 |
| | E | 2.0 | 2.2 | 2.0 | 2.0 | 1.9 | 1.9 | 2.4 | 2.4 | 0.5 | 0.3 |
| | Tukey Value* | 0.3 | 0.6 | 0.5 | 0.6 | | | | | | |
| | F-Test | 2.2 | 1.2 | 3.8 | 2.0 | | | | | | |
| | A | 1.0 | 1.3 | 1.6 | 1.5 | 1.0 | 1.2 | 1.0 | 1.7 | 0.5 | 2.3 |
| | B | 1.2 | 1.1 | 1.3 | 1.3 | 1.1 | 1.2 | 1.3 | 1.7 | 0.3 | 1.2 |
| 15-30 | C | 1.2 | 1.7 | 1.9 | 2.1 | 2.0 | 1.5 | 1.1 | 1.8 | 0.6 | 3.4 |
| | E | 1.4 | 1.2 | 1.2 | 1.4 | 1.2 | 1.2 | 1.4 | 1.7 | 0.4 | 0.7 |
| | Tukey Value* | 0.3 | 0.4 | 0.4 | 0.7 | | | | | | |
| | F-Test | 2.4 | 5.0 | 4.3 | 2.5 | | | | | | |

*All Tukey values are calculated at the 5% level.

Table C9--Extractable Soil Mineral Nitrogen (ppm)

| Block | 1975 | | | | | 1976 | | | | 1977 | | | | Tukey Vale | F-Test |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | July | Aug. | Sept. | Oct. | Nov. | May | Aug. | Sept. | Oct. | May | June | July | Oct. | | |
| A | 5.4 | 5.1 | 6.5 | 4.4 | 4.9 | 6.7 | 2.3 | 3.4 | 2.7 | 4.2 | 6.3 | 5.0 | | 2.4 | 8.3 |
| B | 6.3 | 5.7 | 5.8 | 5.3 | 7.5 | 7.7 | 1.9 | 3.8 | 2.3 | 4.4 | 6.8 | 5.1 | | 2.9 | 10.1 |
| C | ... | 5.6 | 5.6 | 5.8 | 5.4 | 7.7 | 3.1 | 3.4 | 2.8 | 4.6 | 5.5 | 6.3 | | 3.1 | 5.5 |
| D | ... | 5.0 | 5.1 | 5.8 | 4.8 | 4.1 | 3.0 | 2.8 | 2.3 | 3.8 | 3.6 | 4.1 | | 2.1 | 7.6 |
| Tukey Value* | | 2.0 | 2.6 | 2.2 | 2.4 | 2.9 | 1.3 | 1.1 | .9 | | | | | | |
| F-Test | | 0.4 | 0.6 | 1.2 | 4.0 | 2.6 | 2.5 | 1.0 | 1.1 | | | | | | |

*Tukey values are calculated at the 5% level.

## Cooperation and Coordination

Support and coordination provided by the Douglas-fir Tussock Moth Expanded Research Program was excellent. Both principal investigators on this project have enjoyed and value the experience of working with other program investigators, particularly those outside our own specialties. We feel this experience of cooperation will be very valuable to future research studies.

Coordination of this project with other studies that have been initiated at our study site have been successful. We feel there were some opportunities neglected by other investigators who were interested in conducting studies at our study site. However, time and distance may have been prohibitive in some cases.

The use of graduate students on this type of study has been valuable. Coordination of studies within a project of this size was extremely necessary because of the traditional time frame by which graduate students conduct their thesis project. Having the graduate student work at field locations away from the university during the summer months is an excellent work experience opportunity for the student.

## Special Problems

The most significant problems encountered in conducting this research project were:

1. The length of the study was not long enough to establish trends in the movement of nutrients in the defoliated material through the forest floor and into the mineral soil. Further research in this area is anticipated.
2. Non-compliance of contract by data acquisition system manufacturer to provide equipment on agreed schedule.
3. Difficulty in aerially applying to exact quantity of chemical defoliant to simulate stand conditions similar to those following Douglas-fir tussock moth defoliation.
4. Loss and no permanent replacement of a Forest Service technician who was scheduled for 12 percent of his time on this project. Some compensation was made by Program Management to provide support funds for temporary employees.
5. [redacted] Sixteen hundred computer cards of stand analyses data to be prepared by October 1, 1977, were not completed and returned to the principal investigator until December 5, 1977.
6. Completing the final report on December 31 following a very active field season.

Although several of the problems encountered were rather frustrating, none were found to be insuperable nor did they significantly affect the quality of the research.

Expected Publications

Klock, G. O., and T. L. Jones. 1976. Physical disturbance of soil by salvage logging in the Oregon Blue Mountains. (Abstract) Northwest Scientific Association, Cheney, Wash., March 26-27, 1976.

Smith, Ronald M. 1977. Changes in levels of extractable nutrients of a forest floor and soil accompanying defoliation. M.S. Thesis, Washington State University, Pullman.

Huang, Chi-Hua. 1977. Some changes in energy balance of a forest floor with defoliation. M.S. Thesis, Washington State University, Pullman.

Klock, G. O., and C. Huang. 1977. Some early effects of conifer defoliation on microclimate. Agronomy Abstracts, p. 181.

Lopushinsky, W., and G. O. Klock. 1978. Effects of defoliation and sap flow velocity in grand fir. (Abstract) Northwest Scientific Association annual meeting.

Lopushinsky, W., and G. O. Klock. 1978. Effects of defoliation on sap flow velocity in grand fir. USDA Forest Serv. Res. Note PNW-

Klock, G. O., and C. Huang. 1978. Influence of defoliation on soil water use by conifers. USDA Forest Serv. Res. Note PNW-

Klock, G. O., and C. Huang. 1978. Influence of conifer defoliation on microclimate. Agricultural Meteorology.

McNeal, B. L., R. M. Smith, and G. O. Klock. 1978. Influence of conifer defoliation on extractable nutrients of a forest floor. Soil Science Society of America Journal.